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IMPROVING BICYCLE INFRASTRUCTURE WITH THE USE OF BICYCLE SHARE TRAVEL DATA

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IMPROVING BICYCLE INFRASTRUCTURE WITH THE USE OF BICYCLE SHARE TRAVEL DATA

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in Civil Engineering in the
College of Engineering
at the University of Kentucky

By

Jennifer Mintao Weast

Lexington, Kentucky

Director: Dr. Nikiforos Stamatiadis, Professor of Civil Engineering

Lexington, Kentucky

2019

ABSTRACT OF THESIS

IMPROVING BICYCLE INFRASTRUCTURE WITH THE USE OF BICYCLE SHARE TRAVEL DATA

Bicycling as a mode of transportation has been increasing in recent years due to its environmental and health benefits. The availability of bicycles through bicycle share programs has made bicycling a more viable option. With this increase, there is a need for complementary improvements of bicycle infrastructure. Many local and regional transportation agencies are recognizing this need and developing a master plan or safety action plan to improve the city's bicycle and walking facilities. This study examines bicycle travel demands and travel patterns in Lexington, Kentucky as generated by SPIN bicycle share users. It is hypothesized that the SPIN users emulate bicycle users on and around the University of Kentucky campus. Therefore, analyzing their travel patterns will provide a valuable understanding of bicycle demand and infrastructure needs. To identify such demand, travel patterns and routes were compared to the existing bicycle infrastructure in order to determine improvement needs with an ulterior goal to increase bicycling as a mode of transportation. The methods of study include five levels of analysis: length and duration, temporal, climatic, point density, and modeling. Recommendations for improving routes and parking facilities have been developed based on analytical methods and results obtained. The findings support the notion that bicycle infrastructure influences the travel paths cyclists take. The research supports the idea that commuters are using SPIN bicycles to chain their trips with transit and completing the last or first section of the trip with a bicycle. It was found that bicycle travel demand fluctuates with weather patterns. Furthermore, future work could use the existing data and conduct a detailed analysis on the individual trip level to determine what percentage of a completed trip was taken on an existing bicycle facility or on a non-facility. These findings may aid transportation planning and city officials to make decisions for expanding the existing bicycle network in efforts to minimize the percentage of cyclists who take a detour and the length of detours when necessary.

KEYWORDS: Bicycle Infrastructure, Bicycle Share, Bicycle Travel Demand,
Geographic Information Systems, Bicycle Safety

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12/16/2019 Date

IMPROVING BICYCLE INFRASTRUCTURE WITH THE USE OF BICYCLE SHARE TRAVEL DATA

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CHAPTER 1. INTRODUCTION

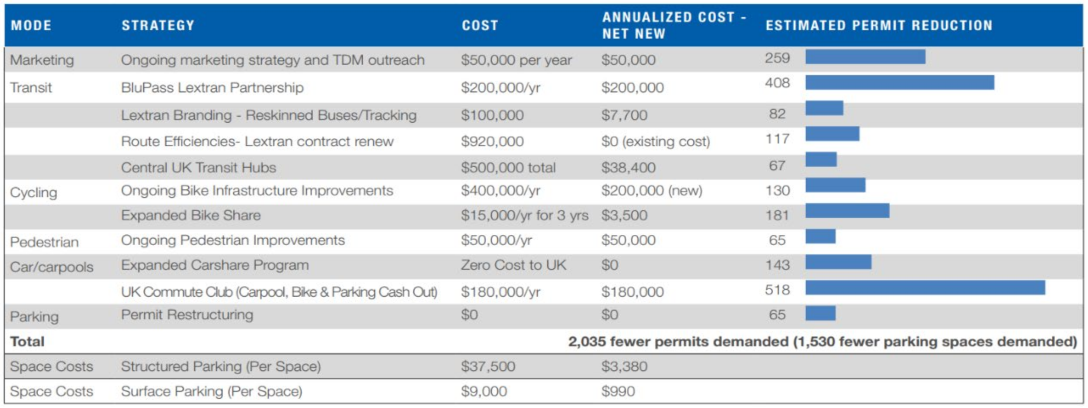
Bicycles as a mode of transportation have been increasing in recent years due to their low travel cost and associated health and environmental benefits (Karanikola 2018). A testament to this is the increased popularity of bicycle share programs in the United States and other countries. However, with this increase in bicycling and bicycle share programs, there is a need for complementary improvements of bicycle infrastructure. Every four years, the American Society of Civil Engineers (ASCE) presents an infrastructure report card which depicts the current condition and performance of the United States infrastructure. Their most recent report showed a grade D for roads (ASCE 2017). A key component in the evaluation of the road infrastructure is public safety. The report notes that in 2015, there were 9.5 percent more pedestrian and 12.2 percent more bicyclist fatalities than in 2014 (ASCE 2017).

In 2017, there were 783 bicyclists and other cyclists killed, which accounted for 2.1 percent of the total traffic fatalities in the United States (NHTSA 2019). Data from the National Highway Traffic Safety Administration (NHTSA; 2019) indicate that urban areas accounted for 75 percent of the bicycle fatalities with 27 percent of the crashes occurring at intersections, 63 percent at non-intersections, and 10 percent at other locations (roadsides/shoulders, parking lanes/zones, bicycle lanes, sidewalks, medians/crossing islands, driveway accesses, shared-use paths/trails, non-traffic-way areas, and other sides). Therefore, it is important to study and understand the growing rates of bicycle travel demands in order for transportation agencies to identify where improvements are needed aiming to improve bicycle infrastructure and safety.

The University of Kentucky (UK) developed a Transportation Master Plan in 2015 that is an overview of the university's transportation services and encompasses all modes of travel including walking and bicycling where one of the guiding principles is to "enhance bicycle access around campus" (UK 2015). However, UK acknowledges the fact that "bicycling can only flourish in a well-planned traffic system that protects bicyclists from vehicles and pedestrians from bicycles". Adequate bicycle parking is also imperative if bicycling is being promoted as a mode of transportation.

The UK Transportation Master Plan identified availability of vehicle parking as a main current and future issue for UK. Students, faculty, and visitors need a place to park their vehicle with a limited number of spaces available. The Transportation Master Plan identifies various transportation demand management solutions to encourage alternative travel modes. One of the strategies is to continue and expand the ongoing bicycle infrastructure improvements which is estimated to reduce the need for 130 vehicle parking permits per year. Furthermore, the expansion of a bicycle share program is another strategy which is estimated to reduce the need for an additional 181 permits per year. These solutions can be seen in Table 1.1 with the estimated cost and number of permits reduced.

Table 1.1 Cost and effectiveness of transportation demand management (UK 2015)



MODE	STRATEGY	COST	ANNUALIZED COST - NET NEW	ESTIMATED PERMIT REDUCTION
Marketing	Ongoing marketing strategy and TDM outreach	$50,000 per year	$50,000	259
Transit	BluPass Lextran Partnership	$200,000/yr	$200,000	408
	Lextran Branding - Reskinned Buses/Tracking	$100,000	$7,700	82
	Route Efficiencies- Lextran contract renew	$920,000	$0 (existing cost)	117
	Central UK Transit Hubs	$500,000 total	$38,400	67
Cycling	Ongoing Bike Infrastructure Improvements	$400,000/yr	$200,000 (new)	130
	Expanded Bike Share	$15,000/yr for 3 yrs	$3,500	181
Pedestrian	Ongoing Pedestrian Improvements	$50,000/yr	$50,000	65
Car/carpools	Expanded Carshare Program	Zero Cost to UK	$0	143
	UK Commute Club (Carpool, Bike & Parking Cash Out)	$180,000/yr	$180,000	518
Parking	Permit Restructuring	$0	$0	65
Total			**2,035 fewer permits demanded (1,530 fewer parking spaces demanded)**	
Space Costs	Structured Parking (Per Space)	$37,500	$3,380	
Space Costs	Surface Parking (Per Space)	$9,000	$990	

Bicycle sharing is a bicycle rental service in which bicycles are available for use with a rental fee. These systems have seen an increase in popularity throughout the United States and across the world. The user can find a bicycle either docked at bicycle share stations or parked along random locations (dockless system) and pay a ridership fee in order to use it. These bicycles are intended for short trips, generally between 0.5 and 3.0 miles, within the bicycle share program's jurisdiction. There have been bicycle sharing programs in Washington, DC, Minneapolis, MN, Denver, CO, New York City, NY, Toronto, Canada, and many other cities.

UK and the Lexington-Fayette Urban County Government (LFUCG) partnered to introduce a bicycle share program, called SPIN, to Lexington, Kentucky in July 2018. The bicycle share program was implemented as a pilot program through a company called SPIN. The SPIN bicycle share program is a dockless system where bicycles can be found and left anywhere by following parking rules given by SPIN (LFUCG 2019). Payment to ride a bicycle is similar to other bicycle share programs where an app can be downloaded on a smartphone to locate and pay for a SPIN bicycle ride. An alternative way to pay is to purchase vouchers from the Lexington Transit Center (WKYT 2018). Dockless parking is the only difference as compared to the traditional bicycle share programs previously described. The pilot program was used to determine if the dockless bicycle share would be viable for the city and university with the possibility of future expansion with a larger fleet of bicycles.

This study examines bicycle usage and travel patterns as generated by the SPIN bicycle users. The route data collected through the GPS locator that each bicycle comes equipped with is saved allowing for meta-analysis and compilation of all user data. This provides a unique opportunity to track users and understand how they travel on and around campus. It is hypothesized that the SPIN users emulate general bicycle users on and around campus and therefore, analyzing their travel patterns will provide a valuable understanding of bicycle demand and infrastructure needs. To identify such demand, travel patterns and routes will be compared to the existing bicycle infrastructure to determine improvement needs with an ulterior goal to increase bicycling as a mode of transportation. The bicycle travel demand in the vicinity of UK campus will also be examined to determine how UK can make campus a more bicycle-friendly environment for students, faculty, staff, and the community. The outcome of this study will be an infrastructure priority list for LFUCG and the UK Transportation Services that can be used when improvements in the existing bicycle network are considered. Along with the engineering research and analysis performed on the SPIN bicycle data, Landscape Architecture students also worked on this project through a studio course to prepare models and visual aids for the infrastructure recommendations.

CHAPTER 2. LITERATURE REVIEW

There has been rapid growth of bicycle share programs in the United States and around the world (Meddin and DeMiao 2019). A bicycle share is a service in which bicycles are made publicly available for individuals to use for a short-term rental period. Rental costs may vary from free to a reasonable charge with some discounts given to students and university employees, depending on the company. In 2018, there were 84 million shared micro-mobility trips taken in the United States (NACTO 2019). Shared micro-mobility consists of stationed-based bicycle share, dockless bicycle share, and scooter share programs. Figure 2.1 shows the ridership trends of micro-mobility trips and the data indicates that the number of trips taken in 2018 doubled in comparison to the previous year. Trip purpose trends have changed over the years as the National Household Transportation Surveys (NHTS) have shown an increase in utilitarian cycling such as work, school, or shopping trips (Pucher et al. 2011). However, cyclists with a utilitarian trip purpose need to reach their destinations on time and thus they need more direct routes with lower delays. It is estimated that cyclists are willing to travel about 13.5 percent longer to ride on a more pleasant cycling facility as compared to the shortest path route (Park and Akar 2019).

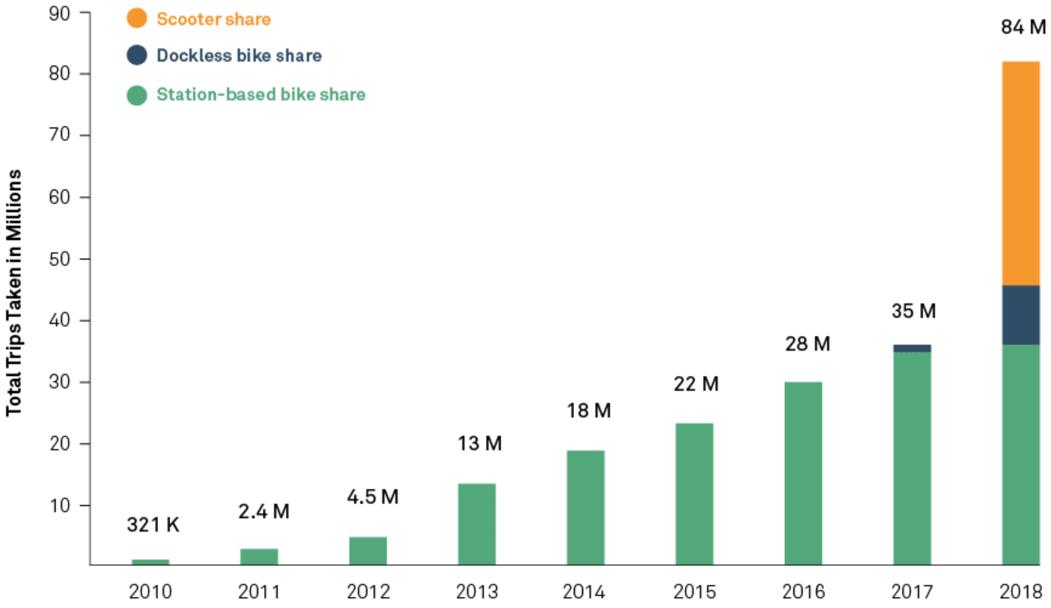


Figure 2.1 Micro-mobility trip trends (NACTO 2019)

The 2009 NHTS reports that the average bicycle trip length is 2.3 miles with an average travel time of 19.4 minutes (NHTS 2009). Bicycle trips to or from work have an average trip length of 3.8 miles and an average travel time of 21.2 minutes (NHTS 2009). A bicycle share program increases the supply and availability of bicycles for all trip purposes, i.e., recreational or utilitarian. However, many communities are questioning whether their existing bicycle facilities are adequate enough to support a bicycle share program and the increased bicycle demands that one brings to a city (Toole Design Group 2012). The emergence of these bicycle share programs is fueling efforts to improve bicycle infrastructure (Toole Design Group 2012). As one bicycle coordinator puts it, “riding a bicycle should not require bravery” (Geller 2009).

Understanding the preferences of bicyclists and route selection is important for decision makers to know where and how to improve infrastructure. Dill and Gliebe (2008) used recorded data of bicycle trips from 164 people in Portland, Oregon and estimated that the median bicycle trip distance was 2.8 miles. Only 5 percent of the trips recorded by the participants were for exercise with a median distance of 8.5 miles. Work-based trips accounted for 25 percent of the recorded trips, 18 percent of the trips were for shopping, dining out, or other personal business, and 12 percent of the trips were for social or recreational purposes. Bicycle travel data can be captured through various technology sources. Smartphone devices such as accelerometers and GPS trackers can be used to measure and track bicycle movements. Stamatiadis et al. (2017) discuss traffic, infrastructure, environmental, and bicycle behavior as information that can be collected by technology sources. Once agencies obtain this data, a better understanding and estimate of travel demand can be made. Other trip attributes can be determined such as route choice or demographics as they relate to trip purpose. It was determined that turn frequency was a negative factor when choosing a route. Another notable finding was that cyclists were willing to go considerable distances out of their way to use a bicycle boulevard or a bicycle path rather than a bicycle lane on an arterial road.

One of the key components in the evaluation of road infrastructure is public safety, which encompasses all modes of travel. Geller (2009), a bicycle coordinator for Portland, Oregon, categorized cyclists into four types based on the comfort or enthusiasm one has for bicycling: "the strong and the fearless," "the enthused and confident," "the interested but concerned," or "no way, no how." The percentages in each group can be seen in Figure 2.2. The target group for improving bicycle infrastructure is ideally the "interested but concerned" which is about 60 percent of the population. These individuals have the ability to move toward the "enthused and confident" group if bicycle infrastructure is improved to their level of comfort. Dill and McNeil (2013) conducted their own study to examine the validity of Geller's four types of cyclists aiming to use the results to identify actions that may increase cycling as a mode of transportation. A random phone survey was used to collect data by asking participants to indicate their level of comfort on a scale of 1 to 4 (1 meaning 'very uncomfortable' and 4 meaning 'very comfortable') regarding several bicycle scenarios, such as different types of facilities based on traffic speeds. The results for the city of Portland and surrounding region were very close to Geller's distribution. Other key findings include that women and older adults (older than age 55) were more likely to fall into the "no way, no how" category and the "enthused and confident" adults were most likely to have cycled to school as a child.

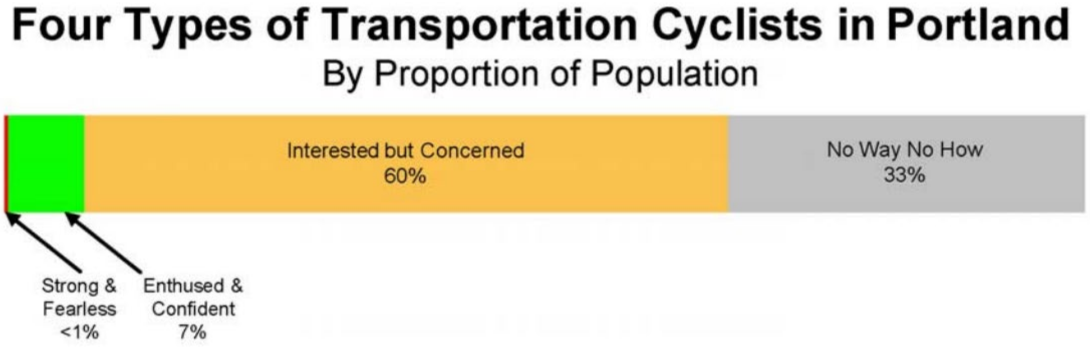


Figure 2.2 Distribution of the four types of cyclists (Geller 2009)

Reynolds et al. (2009) used a literature review to study the impact transportation infrastructure has on bicycling injuries and crashes. The methods used included tabulating results into two categories of infrastructure: intersections and straightaways. Some of the data used to analyze bicycle safety were injuries, severity of injuries, and total number of crashes. The review consisted of 23 papers – eight examining intersections and 15 reviewing straightaways. It was found that roundabouts, in particular multi-lane roundabouts, significantly increased the risk to bicyclists. For straightaways, major roads posed a higher risk than minor roads to bicyclists, but roads with bicycle facilities were associated with lower risks. Sidewalks and multi-use paths had a higher risk associated with crash occurrence.

A survey of bicyclists examined the association between bicycle infrastructure availability and the perception of bicycle safety amongst over 3,000 bicyclists living in six large Canadian and US cities: Boston, Chicago, New York, Montreal, Toronto, and Vancouver (Branion-Calles 2019). Individuals were surveyed about their bicycling habits, safety perceptions, and demographic characteristics. The following question was asked to measure the respondents' safety perception: "Overall, how safe do you think bicycling is in your city?". The responses were based on a 5-point scale with "Safe" being 1 and 2, "Neutral" being 3, and "Dangerous" being 4 and 5. The results showed that 57.9 percent of bicyclists reported bicycling in their city as safe, 15.1 percent as neutral, and 27.0 percent as dangerous. A Bike Lane Score was estimated for various areas within each city where a score of 0 indicates lack of any facilities within 1 kilometer of the area and higher scores indicate greater availability of bicycle infrastructure (Winters et al. 2016). The results showed that participants who came from areas with higher Bike Lane Scores provided a higher response score. This underscores the subjective relationship between infrastructure and consideration of bicycling as a safe transport mode.

Many local and regional transportation agencies are developing a master plan or safety action plan to improve the city's bicycle and walking conditions. Gelinne et al. (2017) has created a guide, titled "How to Develop a Pedestrian and Bicycle Safety Action Plan", to assist agencies with improving safety, examining existing conditions, and using a data-driven approach to match safety programs and improvements with demonstrated safety concerns.

The Reno-Sparks, Nevada region developed a Bicycle and Pedestrian Master Plan in 2017 (RTC 2017). At the time, the region had 446 miles of bicycle lane miles and 78 miles of multi-use paths but recognized the need for improvements. The goal of the proposed bicycle network was to “provide a continuous network of bicycle facilities with the greatest degree of bicycle comfort possible”. The Master Plan also discusses support facilities to bicyclists such as bicycle parking, shower and locker facilities, bicycle repair stations, park and ride facilities, trailhead and staging areas, bicycle share stations, and aesthetically pleasing landscape as additional features that would increase bicycling as transport mode.

The Seattle Department of Transportation (DOT) issued a 2019-2024 Implementation Plan: Seattle Bicycle Master Plan with a vision to make bicycle riding a comfortable and integral part of the daily lives for Seattle people of all ages and abilities (SDOT 2019). Prioritization, in order of highest to lowest weight, of five factors is used when developing this Master Plan: safety, connectivity, equity, ridership, and livability. Over the past 18 months, the Seattle DOT reported a 12 percent increase in bicycle ridership and launched the nation’s largest free-floating bicycle share program as a result of the $12 million investment in bicycle infrastructure, 13 miles of new facilities, and installation of 800 bicycle parking spaces. To continue through 2019, an investment of $76 million over a six-year period will include 50 miles of new bicycle facilities and 29 miles of new projects funded through design and planning.

The city of Copenhagen, Denmark has a successful bicycle network with a goal to become the “world’s best bicycle city” (Gössling 2013). In 2011, “The City of Copenhagen’s Bicycle Strategy 2011-2025” report was issued focusing on four main factors: city life, comfort, speed, and sense of security. The report states that on average, from 2008 to 2010, 36 percent of all trips to work or educational institutions were by bicycle (City of Copenhagen 2011). Furthermore, 17 percent of Copenhagen families own a cargo bicycle which is used to transport children or shopping goods as a car alternative giving a sense of city life to the individuals. Travel time is a major decision factor when choosing to bicycle with 48 percent of Copenhagen cyclists saying that the main reason they choose to cycle is because it is the fastest and easiest way to travel. A sense of security is necessary for most people to choose to cycle, as Geller (2009) alludes to. In 2010, 67 percent of Copenhagen cyclists felt safe in traffic, however one of the goals is to reach 80 percent by 2015 and to increase to 90 percent by 2025.

The emergence of bicycle share has increased the availability of bicycle usage and trip data. Several studies have utilized bicycle share data to evaluate ridership and usage. For example, Xu and Chow (2018) analyzed a bicycle share program to investigate the relationship between bicycle infrastructure and bicycle share ridership. This study was based on longitudinal data using Ridership data from the bicycle share program, Citi Bike, from New York City, New York. A total of 152 weeks of data with an average weekly ridership of 178,880 bicycle trips was evaluated. Ridership patterns were seen to fluctuate based on seasonal patterns. Additionally, the bicycle share program was utilized more on weekdays than on the weekend. Three infrastructure scenarios are used, each with a 10 percent growth of active bicycle stations but the difference in scenarios is how infrastructure investments are introduced. Scenario 1 has no infrastructure investment. Scenario 2 has infrastructure investment as planned, but all in the beginning. Scenario 3 has infrastructure as planned but staged into additions every week. Results show that Scenario 2 has the best outcome for cumulative change in average daily ridership. These conclusions may help city agencies when deciding to introduce a bicycle share program.

The use of GPS tracking through smartphones can be used to evaluate the impact of infrastructure change on cycling behavior. Studying route detours can help city planners and engineers identify where bicyclists are avoiding certain roadway segments. A study in Columbus, Ohio performed a route-level analysis using smartphone GPS tracking data by comparing the bicyclist's chosen route with their associated shortest path alternative (Park and Akar 2018). The study showed that 91.1 percent of cyclists take some sort of detour and cyclists are willing to travel about 13.5 percent longer to ride on a more pleasant cycling facility as compared to the shortest path route. Another study collected data on bicycle usage from Queensland, Australia and produced heat and volume maps of the bicycle patterns (Heesch and Langdon 2016). The Queensland Department of Transport and Main Roads provided information on routes with new bicycle infrastructure during the study period. One finding was that almost two thirds of weekly bicycle trips were re-routed to a new bikeway and off of the previously used road. Furthermore, the data showed that over three months, cyclist counts increased by 15 percent into the city from the southern suburbs after an existing bikeway was expanded, with a decrease in cycling on other major routes.

Fishman et al. (2014) attempt to understand and quantify the factors influencing bicycle share membership in Australia. This study used two bicycle share programs located in Melbourne and Brisbane. Data was collected using an online survey given to individuals with both bicycle share memberships and individuals with no association to either bicycle share program. The survey included various types of information such as helmet wearing, income, and access to a parking area. The study noted that a large percentage (61 percent) indicated that helmet issues were the main barrier. It was found that individuals with relatively higher income had higher odds of having a membership in both programs. Furthermore, those who had access to a parking station within 250 meters of their workplace tended to have higher odds of having a membership.

There have also been studies conducted to identify influencing factors to travel demands for bicycling using traditional methods of data collection from surveys or observations. For example, Schmiedeskamp and Zhao (2016) examined how several seasonal factors affect bicycle ridership using data that was collected for two years from automated bicycle counts at locations in Seattle, Washington. The factors studied include season, temperature, precipitation, holidays, and day of the week. They found that bicycle usage and temperature had a positive correlation along with the number of daylight hours. Bicycle usage and precipitation had a negative correlation as one would expect. This research can be used by policy makers and planners to better understand bicycle travel demands to increase bicycling.

Another traditional method for collecting bicycle demand data is through a survey. Karanikola et al. (2018) conducted a face-to-face questionnaire to 400 residents in a small touristic city in Greece where inner-city public transportation does not exist. The survey consisted of five sections: mode of transportation in the city according to distance, bicycle use in the city and cyclists’ behavior, identification of factors that influence residents to cycle, evaluation of the existing infrastructure, and general respondent demographics. Table 2.1 shows the results of the questionnaire regarding the evaluation of the existing infrastructure for the cycling network in the city, places for parking, training places for children, and the cycling network out of the city. Some of the negative cycling factors that were studied include deficiencies to using bicycles because of insufficient infrastructure, exposure to extreme weather conditions, low speeds, safety hazards, feeling of oddity, physical exhaustion, and lonesomeness on the route.

Table 2.1 Evaluation of the existing cycle infrastructure (Karanikola et al. 2018)

Infrastructure Facilities	Very Good	Good	Mediocre	Bad	Very Bad
Cycle network in the city	7.5%	4.5%	29.2%	32.5%	26.2%
Place for parking	5.8%	5.0%	22.8%	38.8%	27.8%
Training places for children	5.5%	4.8%	17.2%	38.0%	34.5%
Cycle network out of the city	3.2%	4.0%	17.5%	38.0%	37.2%

Dunlap (2015) identifies the need to better understand the understudied group of non-motorized travel, such as biking and walking, in order to allocate funds to improve those modes of travel. The study concluded that transportation engineers and planners will have the ability to eliminate deterrents of non-motorized transportation by identifying the factors that influence biking and walking. Factors studied include weather, land use, and infrastructure. Weather is evaluated based on average temperatures and precipitation and compared to bicycle usage trends. The study confirmed that weather conditions and daily bicycle demands are strongly related as it was illustrated through a statistical model that included weather related variables and day of the week. Urban non-motorized travel is studied using data from a household travel survey conducted in 2006. Data for the roadway network, topography, and crosswalk locations are displayed on ArcGIS. It was concluded that the introduction of non-motorized friendly infrastructure such as bicycle and pedestrian paths is a conventional improvement.

Performing bicycle infrastructure audits is another method to compare and evaluate the bicycle infrastructure systems in different cities or countries. Hull and O'Holleran (2014) conducted bicycle infrastructure case studies for six European cities: Edinburgh, Cambridge, Amsterdam, Rotterdam, The Hague, and Utrecht. Five categories were considered as requirements for properly designed bicycle networks: coherence, directness, attractiveness, safety, and comfort. Additionally, spatial integration, experience, and social economic value were added to evaluate the riders overall experience. One outcome of this research was a list of bicycle infrastructure designs that can encourage bicycling including continuous wide cycle lanes with segregation when possible, especially on truck roads and busy, main roads; clear signage and adequate lighting; the use of high quality material for cycle lanes to offer comfort and reduce maintenance; and end route facilities, such as lockers, showers, and parking facilities, should be discussed with businesses and employers. Other recommendations that are not included in the design of cycle infrastructure but have been noted in case studies include regular maintenance of roads, cycling training for all new drivers and continue cycling training for school children. Dangerous or illegal behaviors of both cars and cyclists, such as cars parking in cycle lanes, dangerous overtaking of bicyclists, cyclists running red lights, and cycling on pedestrian only pavements should be prohibited through enforcement (Hull and O'Holleran 2014).

Two large cities – Beijing and Copenhagen – were examined to learn how an advanced bicycle-friendly city has the ability to spread knowledge to a less advanced city (Zhao et al. 2018). A series of interviews with municipal city planners were conducted in both cities and details on five principles were discussed: cohesion, safety, directness, attractiveness, and comfort. The focus of this study is centered on two main questions: 1. How solutions were identified and what impediments were in implementing them, and 2. Lessons learned. It was concluded that city planners in both cities recognize that safety is the most important of the five factors to consider. However, Copenhagen planners pay high attention to perceived safety as opposed to Beijing planners who do not pay as close of attention to the difference between the actual and perceived safety. Another key difference deals with the cohesion of bicycle-friendly infrastructure. Beijing planners recognize the issue caused when cars are parked illegally in the bicycle lanes, but they anticipate that this problem should be solved gradually. On the other hand, Copenhagen planners give priority to cycling and do not allow space for cars to be parked in the bicycle lanes. In Copenhagen, directness is considered as an important principle as it impacts travel time and efficiency and is applied with the principles of cohesion and safety. However, in Beijing, the principle of directness is not fully considered in the planning environment. It was concluded that the efficiency of bicycle infrastructure planning is related to the level of planning knowledge and experience gained, shared, and embedded at the local level.

In summary, the existing literature provides insight regarding the relationship between bicycle travel demand and bicycle infrastructure supply. The literature indicates that increased infrastructure is an incentive for bicycling while its absence acts as a deterrent. Bicycle share programs have been a popular trend over the past few years, thus increasing the demand for bicycling and number of bicycle trips taken for both commute and recreational purposes. Several local and regional transportation agencies are recognizing the need for bicycle infrastructure improvements by developing a master plan or safety action plan for bicycles and pedestrians. These plans can help agencies not only identify their infrastructure needs, but at the same time prioritize investments and construction in order to maximize benefits and potential increases in bicycle mode-sharing.

The use of GPS devices has been a major aid for tracking bicycle trips and having access to bicycle trip data for research. Bicycle trip tracking can be a tool for city planners to use when determining the best way to allocate funds for improving bicycle infrastructure. The installation of new or improved bicycle infrastructure has the ability to increase bicycle travel demand and efficiency by giving cyclists more direct routes to travel along with a desired level of safety. It is suggested that bicycle facilities on major commuter routes would help reduce detours, specifically during peak hours (Park and Akar 2019).

CHAPTER 3. METHODOLOGY

3.1 Data

The SPIN bicycle share program that was implemented in Lexington, Kentucky was based on a total of 400 bicycles dispersed throughout Fayette County (Thompson 2009). After the first month of implementation, 200 bicycles remained in use with the other 200 bicycles used for parts to repair broken bicycles (Thompson 2019). Lexington, Kentucky has a population of about 324,000 residents (US Census Bureau 2019). UK has an enrollment of about 30,000 students (UK 2019). Furthermore, UK is one of the state's largest employers with more than 12,000 staff and 2,000 faculty (UK n.d.) Modern day bicycle share programs typically use a downloadable application on a smartphone to locate and pay for the bicycle rental. A SPIN bicycle can be located by using the SPIN app that shows a map of the current locations of available bicycles in the vicinity of the user. Each bicycle has a unique barcode-like identifier represented as a Quick Response (QR) code on the back of the seat. Once the QR code is scanned, the bicycle is activated and unlocked. When a SPIN bicycle trip is finished, the bicycle can be locked by pulling down on the locking lever. The GPS location of the SPIN bicycle is recorded every time the bicycle is activated and locked. The start, end, and additional points along the route are recorded through the GPS tracker on the bicycle. This is a dockless system, i.e., the user does not have to rent or return the bicycle to a fixed parking location. SPIN bicycles can be found where the previous users left them, and they can be left anywhere by following parking rules given by SPIN (LFUCG 2019).

The data used in the analysis was obtained from SPIN and consisted of information from individual bicycle trips taken from August 18, 2018 to May 3, 2019. For each SPIN bicycle trip, there is a start and end location represented in latitude and longitude coordinates. Additionally, “route points” are recorded throughout the trip by a GPS tracker device on the bicycle. These points can be seen as a breadcrumb trail to visualize the actual user path taken. The number of route points per trip varies based on the length or duration of the bicycle trip. An example of a completed trip can be seen in Figure 3.1. The green point represents the start location and red point represents the end location of the trip. The gray points represent the intermediate route points that show the user’s actual path. Once the raw data was received from SPIN, the data was sorted in a way that can be plotted in ArcMap using a Python script. The Python script was able to create three feature classes of points: Start Points, End Points, and Route Points. The data for the analysis was based on SPIN bicycle trips taken from August 18, 2018 to May 3, 2019.

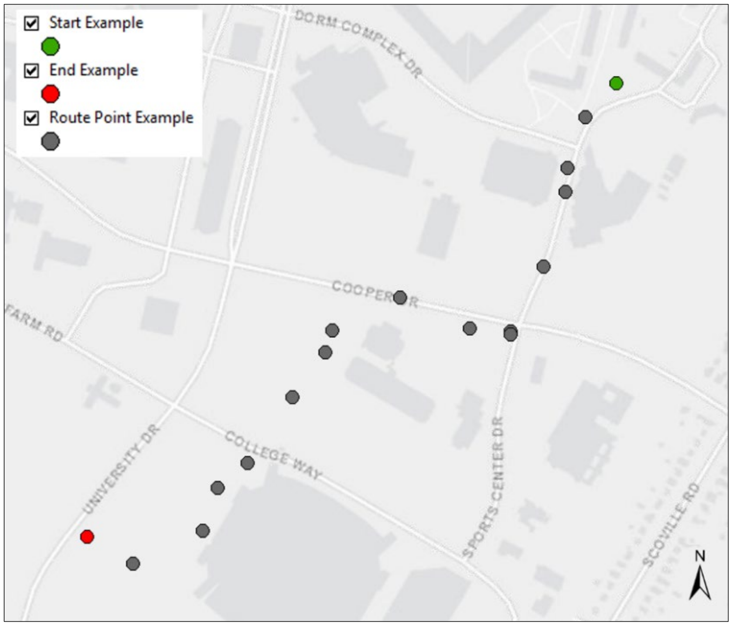


Figure 3.1 Example of a completed SPIN bicycle trip

There were 46,064 Start Points in Fayette County within the analysis period. However, there were almost 3,000 trips that had a route distance of zero or a trip duration of zero. Two additional issues associated with the data are the presence of short distance trips with long duration or long-distance trips with short duration. Both of these indicate that there may be an issue regarding the recorded data that could be attributed to the user not locking the bicycle (long duration) or carrying the bicycle in a vehicle to other locations (long distance over short duration). It was therefore deemed appropriate to establish a reasonable travel distance and duration in order to eliminate such issues. A low speed of 5 miles per hour (mph) was considered appropriate since it is slightly higher than walking speed (approximately 2 to 3 mph) while a high speed of 12 mph was considered the cut off point for unusually fast trips. Using the upper speed cutoff value of 12 mph, a total of 4,590 trips were eliminated. It should be noted that the trips with lower than 5 mph speeds were still used in the analysis of the routes but not considered in the estimation of average rental and trip durations. Once the trips with zero distance or zero duration and the trips with unusually high travel speeds were removed, a total of 38,505 trips were used in the analysis.

3.2 Analysis Approach

ArcMap is used to display the SPIN bicycle trip data in a way that can be visually represented. ArcMap is a geospatial processing program and part of ESRI’s ArcGIS application (ESRI 2016). This application allows the GIS data to be displayed, explored, and edited to create map layouts (ESRI 2016). A projected coordinate system is used to show an accurate representation of the city of Lexington. The projection used for the data points is “NAD 1983 (2011) State Plane Kentucky FIPS 1600 (US Feet)”. Points are grouped in feature classes to allow for a systematic display and analysis. The three primary feature classes are Start Points, End Points, and Route Points. With these three feature classes, further geoprocessing tools can be used to extract useful information. For example, there were SPIN bicycle trips recorded and taken outside of the Lexington-Fayette area. Those points are excluded from the data analysis because the scope of the project focuses on Lexington and UK campus areas.

The three feature classes are added to the ArcMap database. As previously mentioned, there are some SPIN bicycle trips that were taken in other parts of Kentucky such as Louisville, Kentucky and Richmond, Kentucky. The route points can be seen traveling along interstate highways and other high-speed roads. To eliminate these points, any data points falling outside of the Fayette County boundary were removed.

A Fayette County shapefile was obtained from US Census Bureau, Department of Commerce and used to select only the points (Start, End, Route) falling within the county boundary. Target layers were created for the Start, End, and Route points and they were combined with the Fayette County boundary (i.e., source) layer to generate a new layer consisting only of the points within the county.

Furthermore, UK has provided a shapefile of the campus boundary that was used to determine the number of SPIN bicycle trips that started and ended on campus. The same process was followed here as well by using the UK campus boundary as the source layer. This process resulted in a total of 29,472 SPIN bicycle trips originating within the UK campus boundary and a total of 27,585 SPIN bicycle trips ending within the UK Campus boundary. This shows that there were several SPIN bicycle trips that started on UK campus but then ended somewhere else. This suggests that students may have taken a SPIN bicycle from UK campus to their off-campus housing but did not make the trip to campus on a SPIN bicycle.

Point density maps are used to visually depict the number of occurrences of a feature at the same location. A point feature is a GIS object that has an X and Y location coordinate and is usually represented as a “point” or dot on a map (ESRI 2018). However, multiple points at the same location are plotted on top of each other and thus it is difficult to distinguish one location with a large number of points from another location with few points. The point density is used to address this issue through visualizing the data and depicting locations where there could be several points at the same location. The input is a cluster of points with each point representing a single event. The output is a colored cell. The cell represents the number of points within the neighborhood divided by the area of the neighborhood. Figure 3.2 shows how a cluster of points can be represented as a point density output. Darker color cells have more points in the neighborhood as compared to a lighter color cell. A point density is represented as a raster image that overlays the base map. To better understand the story behind the point density, several symbology techniques can be used. For example, the color scale should be chosen that appropriately represents the data such as dark to light, red to green, etc. Several point density maps will be created to show high density SPIN bicycle activity in Lexington and UK campus. A point density using SPIN bicycle trip data will have the units of bicycles per specified radius.

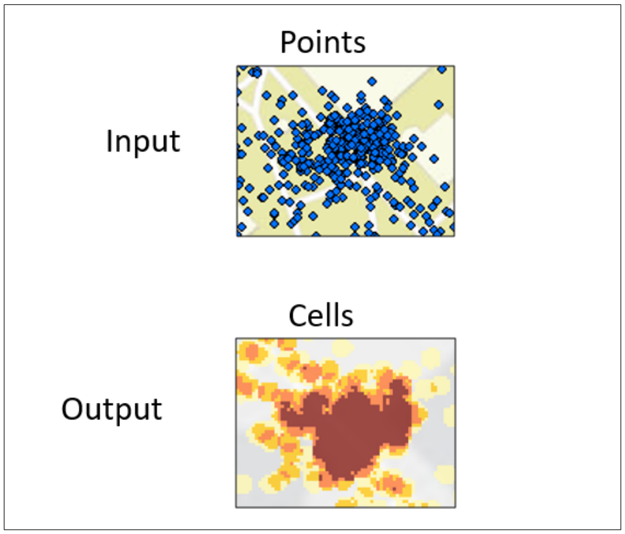


Figure 3.2 Example a point density depiction

The number of SPIN bicycle trips per day can be determined and used in a model for predicting the number of trips taken per day. Literature findings have suggested that weather and daily bicycle trips are strongly correlated. Trip characteristics, such as trip duration and route distance, will be tested to determine if duration or distance affects the number of daily trips taken and which one is a better predictor. The models will be linear in nature and developed using several explanatory variables such as weather-related data and trip characteristics. These models can be used to identify how external factors are correlated when predicting bicycle travel demand. The models will be compared based on their predictive power, significance of variables, and examination of how well variables match prior findings and rational tests. The stronger model will be selected as the representative model for predicting the number of daily SPIN bicycle trips. To ensure the validity of the model, a validation and training approach was undertaken where 90 percent of the data was used for model development and the remaining 10 percent was used for estimating the number of trips per day and compared to the actual data.

CHAPTER 4. ANALYSIS

This section presents the analysis undertaken to determine the travel patterns of the SPIN bicycle share users and identify the infrastructure needs to address them.

4.1 Length and Duration

The SPIN bicycle trip data has been analyzed based on trip length and duration (travel time). Literature findings have suggested that the average bicycle trip length ranges from 2.3 to 2.8 miles with an average travel time of about 20 minutes. The collected SPIN bicycle data shows similar trends to these. As noted in the previous section, the data was filtered considering only trips with travel speeds ranging from 5 to 12 mph. This was done in order to capture only the completed trips that have reasonable trip lengths with associated travel times. For example, a trip with a distance of 1.5 miles completed in 120 minutes most likely was the result of the rider forgetting to lock the bicycle and end the trip. The majority of the SPIN bicycle trips with travel speeds ranging from 5 to 12 mph (95.6 percent) taken in Fayette County during the analysis period had a distance of 2.5 miles or less (Figure 4.1). Furthermore, 94.6 percent of the SPIN bicycle trips had a travel time of 20 minutes or less (Figure 4.2).

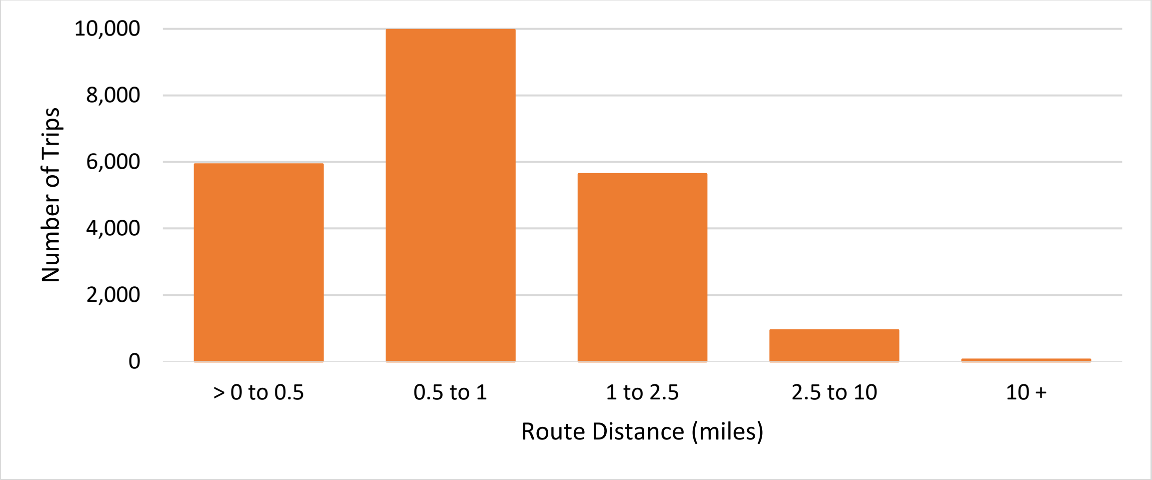


Figure 4.1 SPIN bicycle trips by route distance

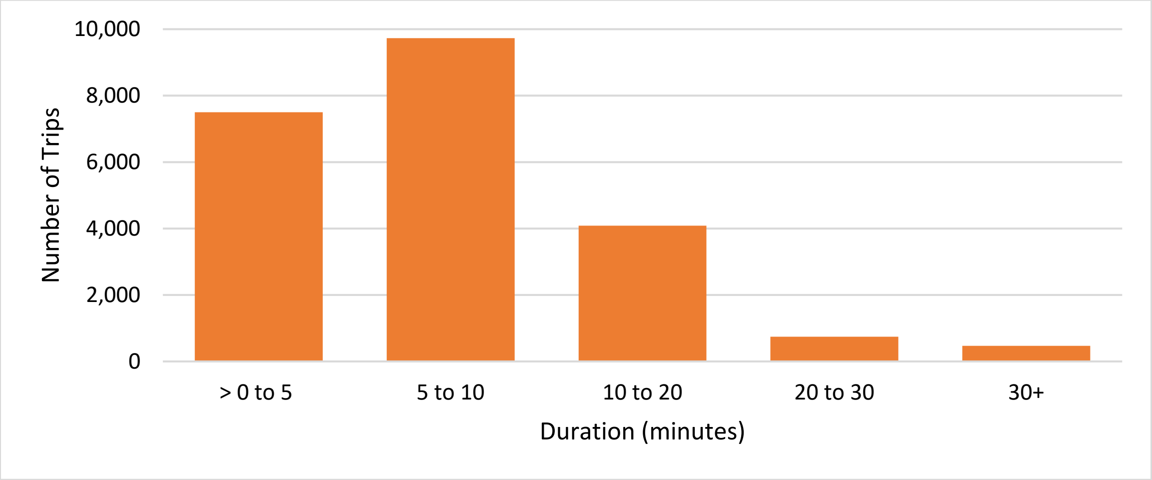


Figure 4.2 SPIN bicycle trips by duration

The analysis also considered the day of week the trip was taken, i.e., weekday or weekend. Weekday trips had an average trip length of 0.9 miles with an average travel time of 7.9 minutes. Weekend trips were longer in both distance and duration with an average trip length of 1.2 miles and an average travel time of 10.9 minutes. Weekday trips are likely the result of utilitarian trips to work or school while weekend trips may be for recreation or exercise purposes, thus resulting in longer trips.

4.2 Temporal Analysis

The trip data has been further analyzed based on the day of the week, month, and college semester to determine any temporal trends in ridership and usage. The data used in this portion of the analysis consists of SPIN bicycle trips taken during the analysis period while excluding trips with a travel speed or travel time of zero and excluding trips with a travel speed exceeding 12 mph. Trips with an unusually long duration are still considered in this analysis because trip duration does not affect the count and route taken when considering temporal factors. Figure 4.3 shows the number of SPIN bicycle trips per semester by the day of the week. The enrollment numbers are large because one student may be enrolled in more than one class per day. Wednesdays had the greatest number of SPIN bicycle trips taken with the weekends having the least amount of usage. The fact that UK has a large population of students who generally are on campus on weekdays could explain the weekday-weekend differences.

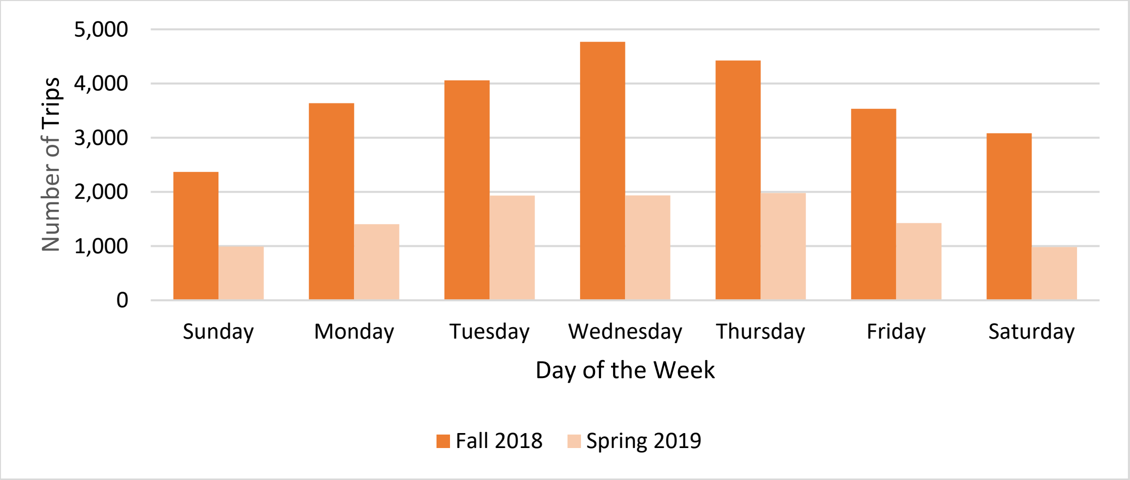


Figure 4.3 Number of SPIN bicycle start trips by day of the week

Figure 4.4 shows the monthly usage of SPIN bicycles with the winter months having a lower number of SPIN bicycle trips than the summer months. The Fall semester had more than double the number of SPIN bicycle trip as compared to the Spring semester. This could be because weather was more enticing in the Fall than in the Spring semester, thus resulting in significantly more trips. Furthermore, the UK course enrollment data shows that there was a larger number of enrolled students in the Fall 2018 semester than the Spring 2019 semester (Table 4.1). This could partially address the variation in monthly SPIN bicycle usage between the fall and spring semester months. Another explanation for the lower SPIN bicycle usage in the Spring semester may be the novelty of the program in the Fall semester and students who arrived back on UK campus wanted to 'try them out' with diminishing marginal utility as the semester and school year continues. Finally, weather conditions could also contribute to these differences, where more inclement weather is typically observed during the spring semester.

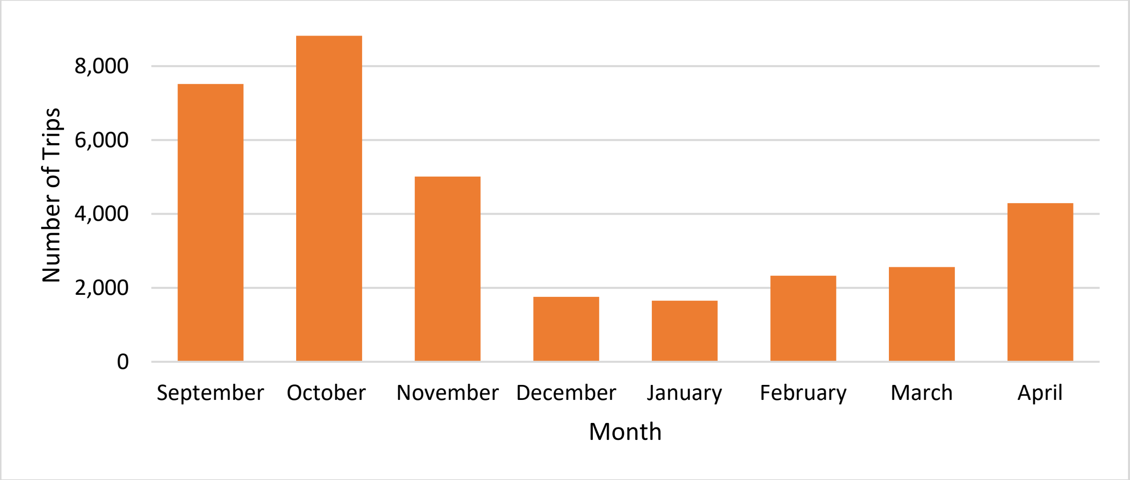


Figure 4.4 Number of SPIN bicycle start trips by month

Table 4.1 Course enrollment data

Day of Week	Number of Enrolled Courses	
	Fall 2018	Spring 2019
Monday	59,470	49,974
Tuesday	55,373	49,164
Wednesday	61,579	51,718
Thursday	54,185	48,254
Friday	42,662	36,463

In order to better understand the daily differences noted in Figure 4.3 and determine whether indeed there is a day of week effect, a rate for the number of SPIN bicycle trips per 1,000 enrolled courses was developed. It can be seen in Figure 4.5 that the rate in the Fall 2018 semester is nearly double the Spring 2019. Furthermore, as Figure 4.3 illustrates, Wednesday appeared to have the highest number of SPIN bicycle trips taken. It was hypothesized that Wednesday had the highest number of enrolled students as some courses have a Monday-Wednesday and Wednesday-Friday schedule; a fact that was verified with the data in Table 4.1. The conversion of the number of trips to a rate per 1,000 students normalized these rates and demonstrated a more uniform distribution throughout the week. There are still differences among weekdays, but these are rather smaller in magnitude than the ones observed in Figure 4.3. Overall, the weekly SPIN bicycle usage rate increase over the course of the week. This trend may be attributed to factors not related to course enrollment such as weather or trip purposes other than going to school.

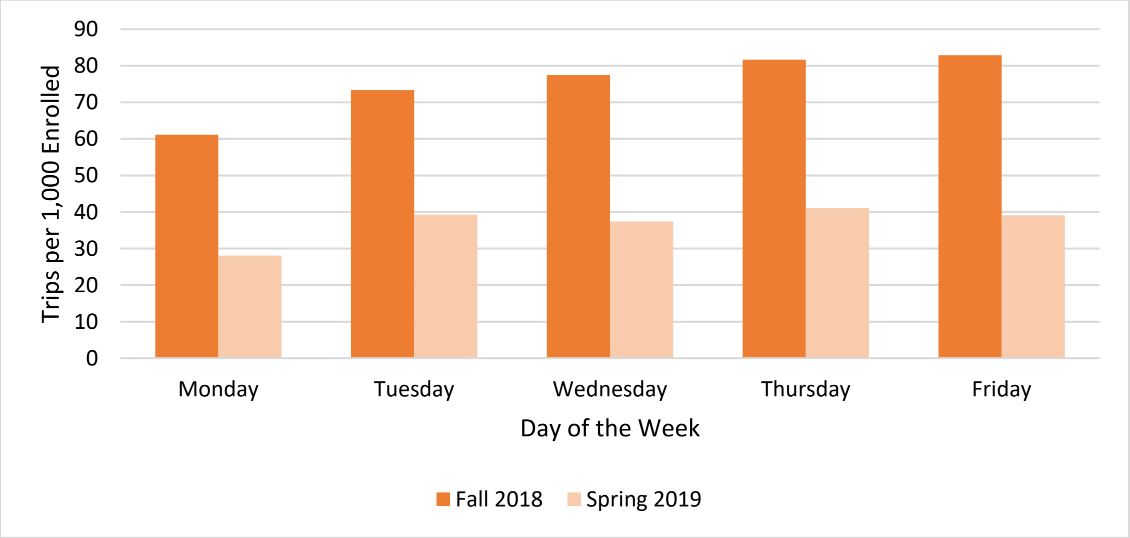


Figure 4.5 SPIN bicycle trips per 1,000 enrolled courses

Overall bicycle usage trends vary throughout the day (Figure 4.6). The highest hourly usage occurs at the evening rush hours around 4:00 PM and 5:00 PM. The morning peak period is from 7:00 AM to 10:00 AM with usage increasing at a steady rate during this period. Weekday hourly distribution can be seen in Figure 4.7 and weekend hourly distribution can be seen in Figure 4.8. Faculty and staff follow a regular work schedule, for example 8:00 AM to 5:00 PM, however, students typically do not have a work-type schedule. This explains the random jumps in SPIN bicycle usage for weekday distribution in Figure 4.7. The large portion of trips taken in the afternoon time may occur when students are finished with classes and have time for recreational or exercise trips. However, the weekend hourly distribution shows a steadier increase in trips throughout the day until around 4:00 PM where the hourly number of trips begins to decrease. This shift in time of day travel patterns may occur because on weekends, people may start their daily routines at a later time, they do not typically have to be their destinations early morning and are not confined in the typical classroom periods and work schedule.

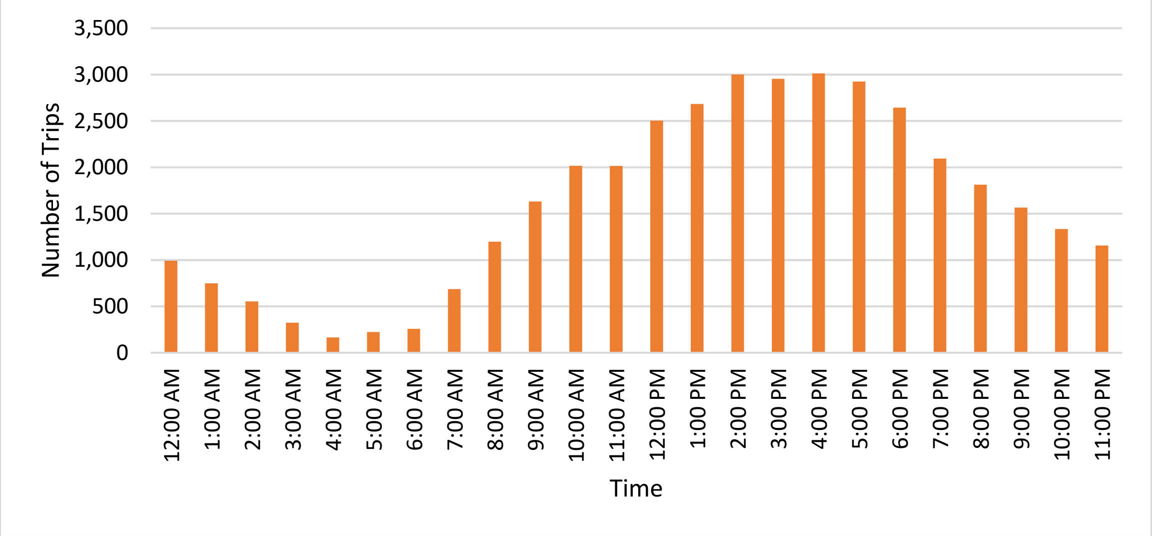


Figure 4.6 Hourly distribution of SPIN bicycle start trips

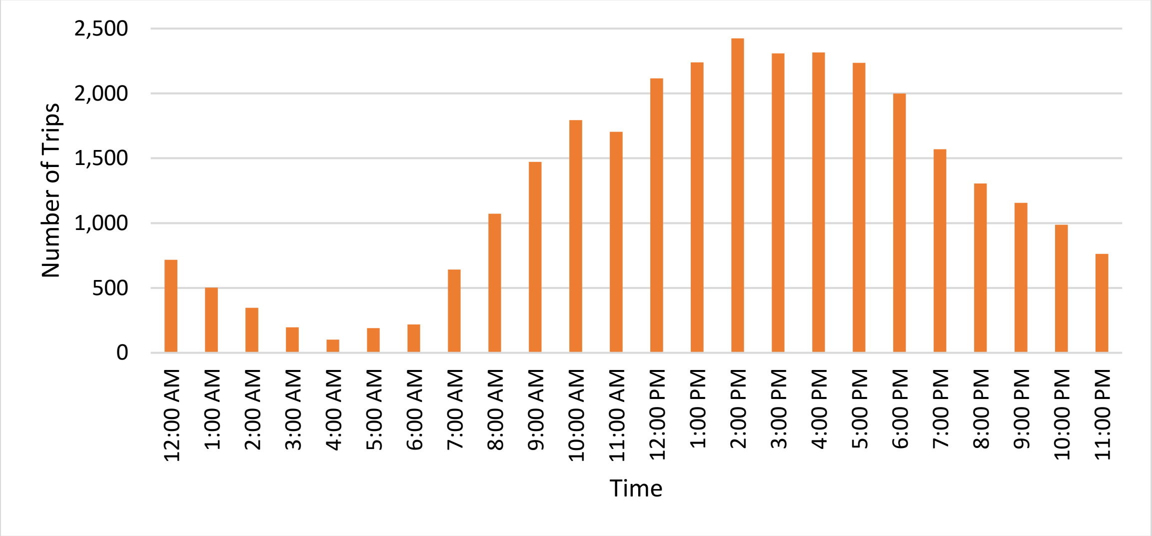


Figure 4.7 Weekday hourly distribution of SPIN bicycle start trips

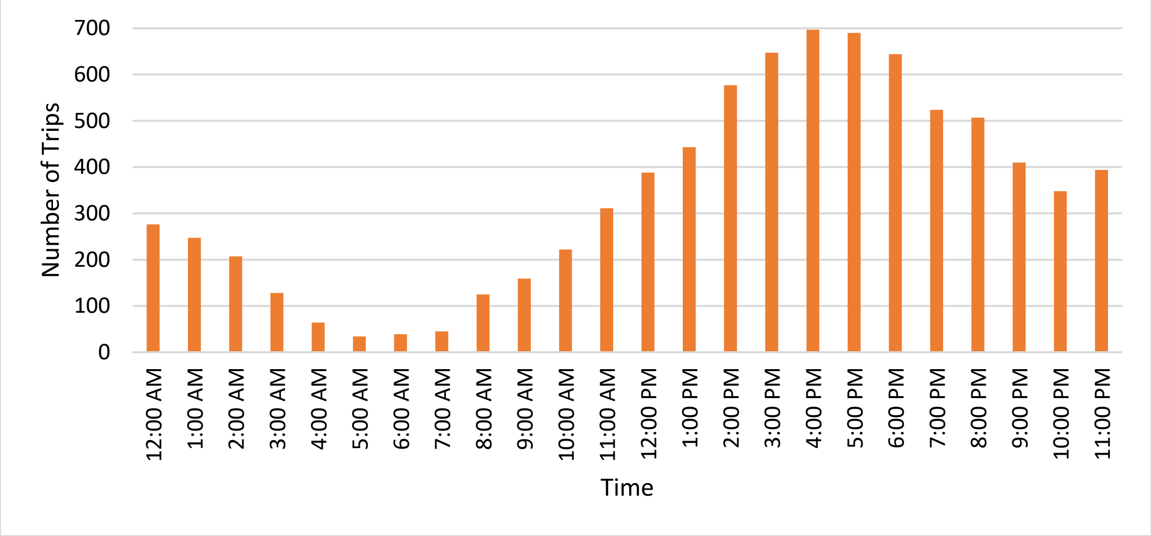


Figure 4.8 Weekend hourly distribution of SPIN bicycle start trips

4.3 Climatic Analysis

The literature indicated that weather affects the choice to bicycle. Weather data has been obtained from the National Oceanic and Atmospheric Administration (NOAA) using the Climate Data Online tool for the analysis time period. The Lexington Bluegrass Airport station is the closest station to downtown Lexington and UK campus. The data obtained included specific weather information for each day such as amount of precipitation, amount of snowfall, average temperature, high and low temperatures, and other various weather characteristics. This data was used to determine any weather patterns that relate to SPIN bicycle usage over the analysis time period.

The data analysis of weather trends shows that there was a significantly higher SPIN bicycle usage during the Fall semester than in the Spring semester. The average temperature in the Fall semester (August 22 to December 14) was 57 degrees while in the Spring semester (January 9 to May 3) was 45 degrees. The average high temperature was only 54 degrees in the Spring semester as compared to 66 degrees in the Fall semester. Figure 4.9 shows the number of trips taken per day and the temperature for the corresponding day. The data shows that the daily bicycle trip counts follow similar trends to the daily average temperatures over the time period.

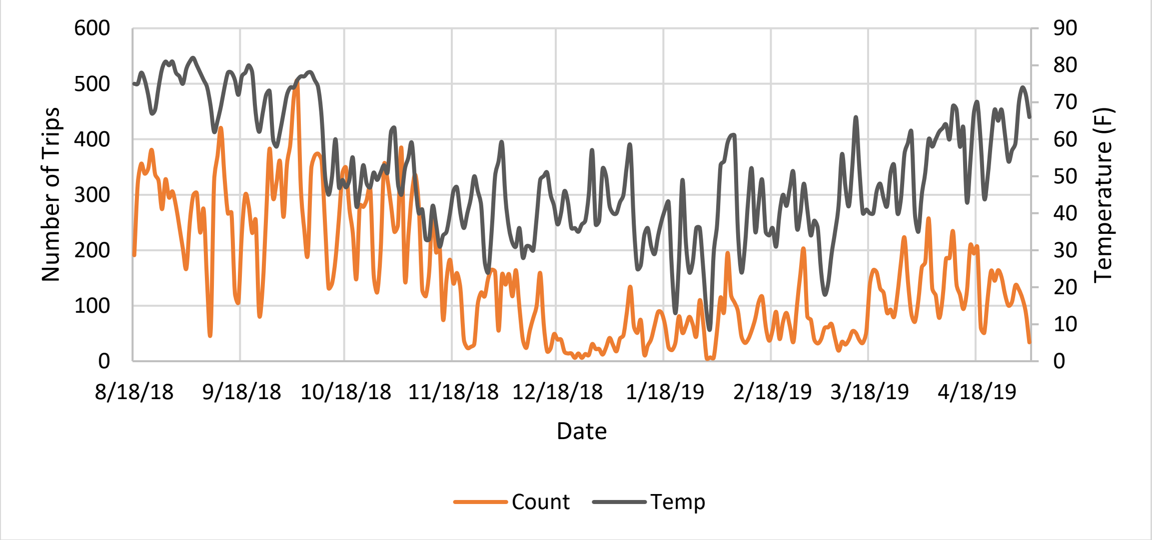


Figure 4.9 Daily SPIN bicycle usage trends with average daily temperature trends

4.4 Prediction Model

Three generalized linear models have been developed for predicting the number of SPIN bicycle trips per day. The purpose of these models is to estimate the demand for bicycling on and around campus as SPIN bicycles are thought to emulate general bicycle usage and patterns. This knowledge could also allow for predicting bicycle demand for specific days in order to eventually aid in determining bicycle infrastructure needs. Several explanatory variables were considered in the analysis: average temperature (degrees Fahrenheit), day the trip was taken (weekday/weekend), average wind speed (miles per hour), amount of precipitation (inches), average route distance (miles), and average trip duration (minutes). The models can be used to determine the level of influence each variable has on cycling.

The data used in the first linear regression model consisted of trips taken in Fayette County during the analysis period while excluding trips with a travel distance or travel time of zero and those with a travel speed exceeding 12 mph. For this reason, the average duration variable was not considered due to potential inaccurate duration estimates.

Table 4.2 shows the model structure, i.e., variables in the model, their coefficients and significance for predicting the number of trips per day. The variables included in the model are average temperature, day of week, average wind speed, precipitation, and average route distance. Model 1 has an R^2 value of 0.523, an Akaike's information criterion (AIC) of 2984.679, and a Bayesian information criterion (BIC) of 3009.550.

Table 4.2 Model 1 parameters

Variables	Coefficients	Significance
Constant	21.853	0.329
Average Temperature (F)	4.513	0.000
Day of Week	-39.924	0.000
Average Wind Speed (mph)	-5.206	0.000
Precipitation (inches)	-31.637	0.007
Average Route Distance (miles)	-43.422	0.000

Model 2 and Model 3 used only the SPIN bicycle trips with travel speeds ranging from 5 to 12 mph in order to determine whether the average trip duration or average route distance is the better predictor of daily number of SPIN bicycle trips. The same four variables were used in both models – average temperature, day of week, average wind speed, and precipitation – with the addition of average trip duration or average route distance.

Table 4.3 and Table 4.4 show the model parameters for each set of variables. The R^2 values for the model including average trip duration (Model 2) and the model including average route distance (Model 3) are 0.487 and 0.496, respectively. The AIC and BIC for Model 2 are 2713.159 and 2738.030, respectively. The AIC and BIC for Model 3 are 2708.247 and 2733.117, respectively.

Table 4.3 Model 2 parameters for average trip duration

Variables	Coefficients	Significance
Constant	45.772	0.001
Average Temperature (F)	2.370	0.000
Day of Week	-27.671	0.000
Average Wind Speed (mph)	-2.817	0.001
Precipitation (inches)	-16.644	0.017
Average Trip Duration (minutes)	-4.901	0.000

Table 4.4 Model 3 parameters for average route distance

Variables	Coefficients	Significance
Constant	50.909	0.000
Average Temperature (F)	2.368	0.000
Day of Week	-26.941	0.000
Average Wind Speed (mph)	-2.815	0.001
Precipitation (inches)	-17.007	0.014
Average Route Distance (miles)	-47.895	0.000

The constant variable represents the number of daily SPIN bicycle trips that would be taken without any adjustment for the other variables. The average temperature has a positive correlation with daily usage which means that the number of trips increase as the temperature increases. Average wind speed and precipitation have a negative correlation as one would expect, meaning that the higher average wind speeds and greater amounts of precipitation result in a lower number of daily trips. All three temporal variables conform to a priori expectations: adverse weather conditions result in fewer trips. Day of the week has a negative correlation which means that there fewer trips during the weekend than during a weekday. This finding is consistent with prior research conclusions. Lastly, average trip duration and average route distance also have a negative correlation. Longer duration trips would result in a lower number of overall trips. The same is observed with the longer distance trips.

Model 2 and Model 3 are compared since they use the same set of data in the regression – trips with travel speed ranging from 5 to 12 mph. The model that includes average route distance (Model 3) servers as better model for predicting the number of SPIN bicycle trips for any given day based on the comparison of R^2 values, AIC, and BIC. Based on this comparison, Model 1 is more appropriate for prediction since it is based on a larger data set and has a higher R^2 value than Model 3.

To evaluate Model 1, a validation and training approach was taken where 90 percent of the data was used for Model 4 and the remaining 10 percent was used for estimating the number of trips per day. The average distance was used as the trip predictor based on the conclusions drawn from the comparison of Model 2 and Model 3. The coefficients for Model 4 are shown in

Table 4.5; the model has an R^2 value of 0.530, AIC of 2701.397, and BIC of 2725.554. The estimated number of trips was compared to the actual number of trips for the remaining 10 percent of the data. The range of the differences resulted in a maximum overestimation of 63 trips and a maximum underestimation of 207 trips. The average of the differences is an underestimation of 15 trips. Table 4.6 shows a comparison of the four models based on R^2, AIC, and BIC.

Table 4.5 Model 4 parameters for training approach

Variables	Coefficients	Significance
Constant	25.954	0.269
Average Temperature (F)	4.514	0.000
Day of Week	-38.644	0.001
Average Wind Speed (mph)	-5.468	0.000
Precipitation (inches)	-31.997	0.008
Average Trip Duration (minutes)	-43.338	0.000

Table 4.6 Model comparison

	Model 1	Model 2	Model 3	Model 4
R^2	0.523	0.487	0.496	0.530
AIC	2984.679	2713.159	2708.247	2701.397
BIC	3009.550	2738.030	2733.117	2725.554

Based on Table 4.6, Model 4 serves as the best prediction model and can be used to predict the number of daily SPIN bicycle trips with a set of variables known to affect trip choice. Model 4 is selected because it has the highest R^2 value and the lowest AIC and BIC. The complete regression equation can be seen below. Transportation agencies may use this knowledge of the various explanatory variables to predict the travel demand for bicycle facilities based on location specific weather.

$$Count = 25.954 + 4.514(TEMP_{avg}) - 38.644(\mathrm{DAY}) - 5.468(WIND_{avg}) - 31.997(PRECIP) - 43.338(DIST_{avg})$$

4.5 Point Density Analysis

The SPIN bicycle travel patterns are displayed using point density maps to visually show locations of high-density bicycle traffic. The data used in the point density analysis consists of trips taken during the analysis period while excluding trips with a travel speed or travel time of zero and excluding trips with a travel speed exceeding 12 mph. Trips with an unusually long duration are still considered in this analysis because trip duration does not affect the path taken by a rider.

Figure 4.10 is a point density map of all points (Start, End, and Route). This map shows the general locations of bicycle usage as well as those with heavy bicycle usage. This map and the others to be displayed in the following sections can be used to determine locations and routes which may need bicycle infrastructure improvements. The point density maps with their color scales depict level of overall usage and one can observe the various bicycle routes, such as those along Avenue of Champions and Rose Street that have high usage. Similarly, several sidewalks on campus and in the area surrounding the campus show a large concentration of bicycle usage.

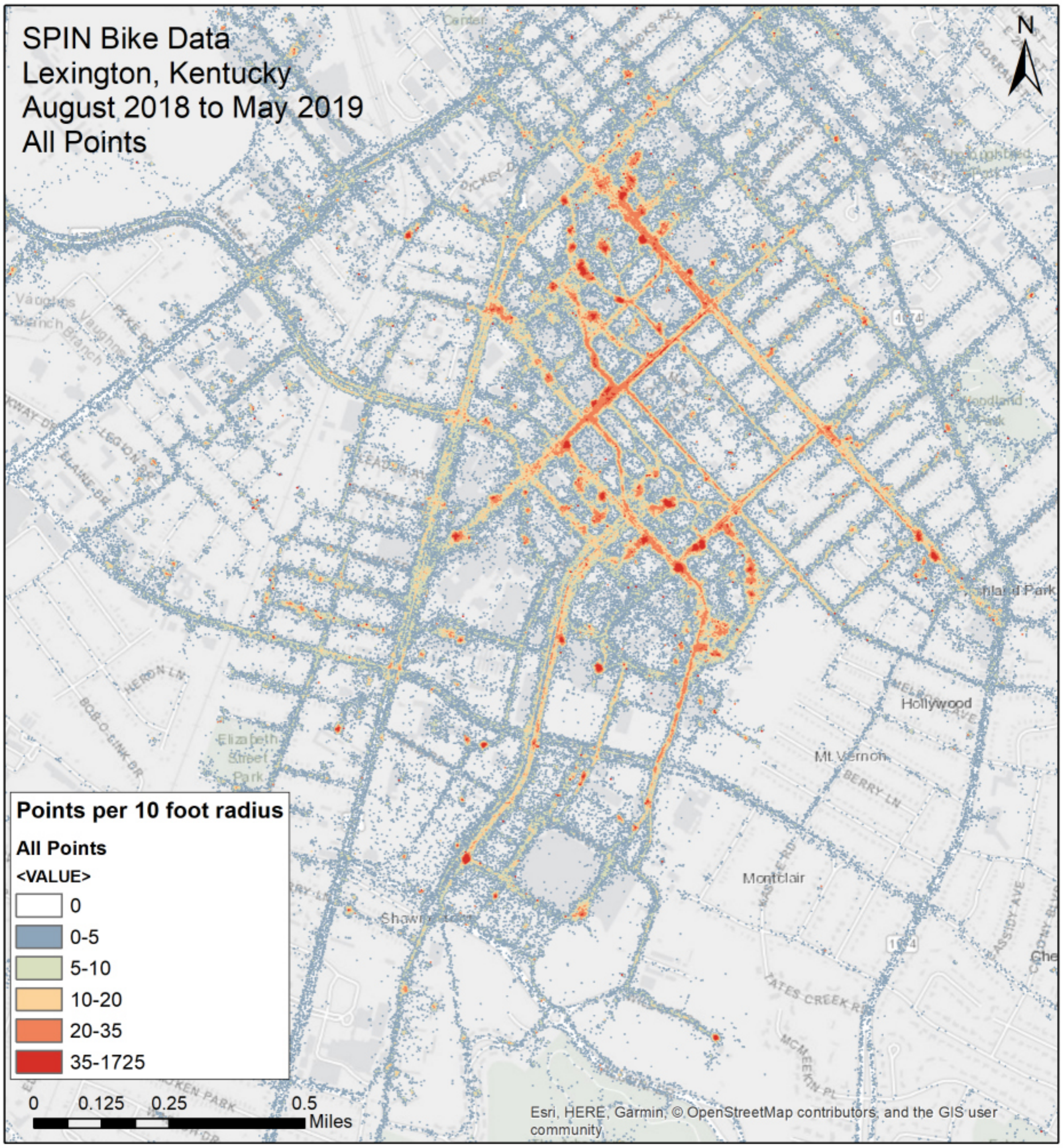


Figure 4.10 All Points point density map

Figure 4.11 is a point density map of only the Start and End points. This map shows the origin and destinations of a bicycle trip, which can be used to define the purpose of bicycle trips. Most of the high-density areas appear near major classroom buildings and residence halls on UK campus. This pair of origin and destination suggests that students are cycling to and from class or from their residence hall to class and back. The southernmost red cluster appears near the bus stop for the stadium parking lot which suggests that commuters (faculty or students) begin or end a trip at the bus stop.

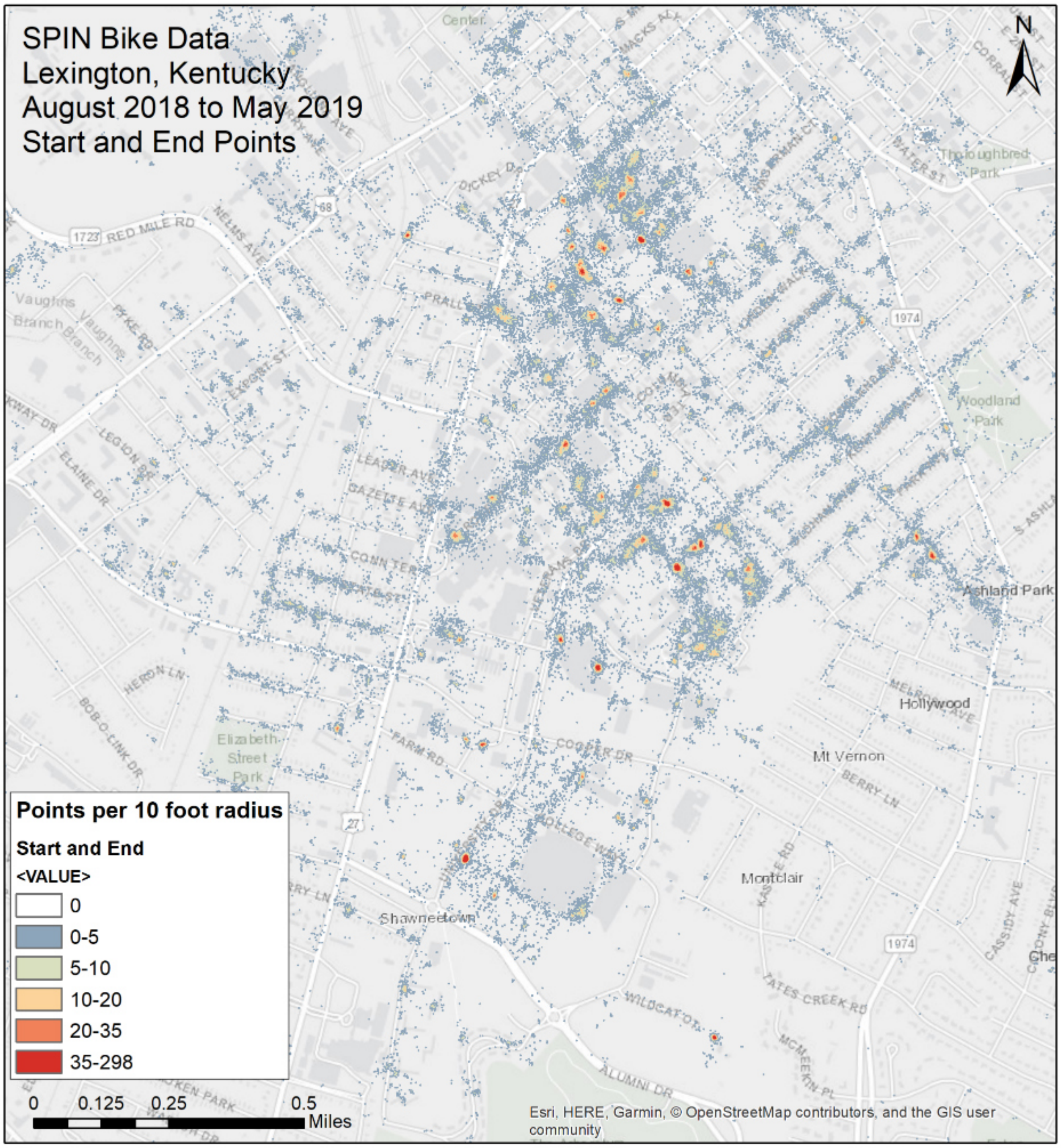


Figure 4.11 Start and End point density map

4.4.1 Routes Analysis

Critical to understanding and determining bicycle infrastructure improvements is the evaluation of existing bicycle facilities and how they are currently function. The use of SPIN bicycle trip data can be used determine how users utilize segments of the roadway system and bicycle infrastructure. The existing bicycle paths in Lexington, Kentucky were obtained from the LFUCG Division of Planning in a digital format as a shapefile to be used in ArcGIS. The first step is to display the shapefile to the map and determine the facilities that will be analyzed. The facilities denoted in the attribute table showed several biking and pedestrian facilities such as bike lane, buffered bike lane, shared use path, walking trail, mowed path, etc. The paths that are designated for bicycle use were selected and those paths are used in the evaluation of existing bicycle facilities.

The facilities that have been selected to evaluate based on their description in the attributes table include: Existing bike lane, existing buffered bike lane, existing paved path, existing sharrow, existing signed bike route, existing shared use trail, funded bike lane, funded buffered bike lane, funded on road bike facility, funded shared use trail, funded sharrow, funded signed bike route, proposed bike lane, proposed bike lane and trail, proposed on road bike facility, proposed shared use trail, proposed signed bike route, unfunded shared use trail.

Once the bicycle facilities of interest have been selected, the travel demand on these routes can be determined and depicted on a map. A point density map will be used to show the intensity of bicycle travel on these selected bicycle facilities. The first part will be examining how the existing bicycle routes are being utilized. Figure 4.12 is a map that shows a point density of SPIN bicycle Route Points for only the trips completed along an existing bicycle facility. Routes in the vicinity of the UK campus that show a high travel usage are along the Avenue of Champions/Euclid Avenue, Rose Street, Woodland Avenue, and Columbia Avenue. It can be seen that routes further away from the UK campus have less bicycle travel usage.

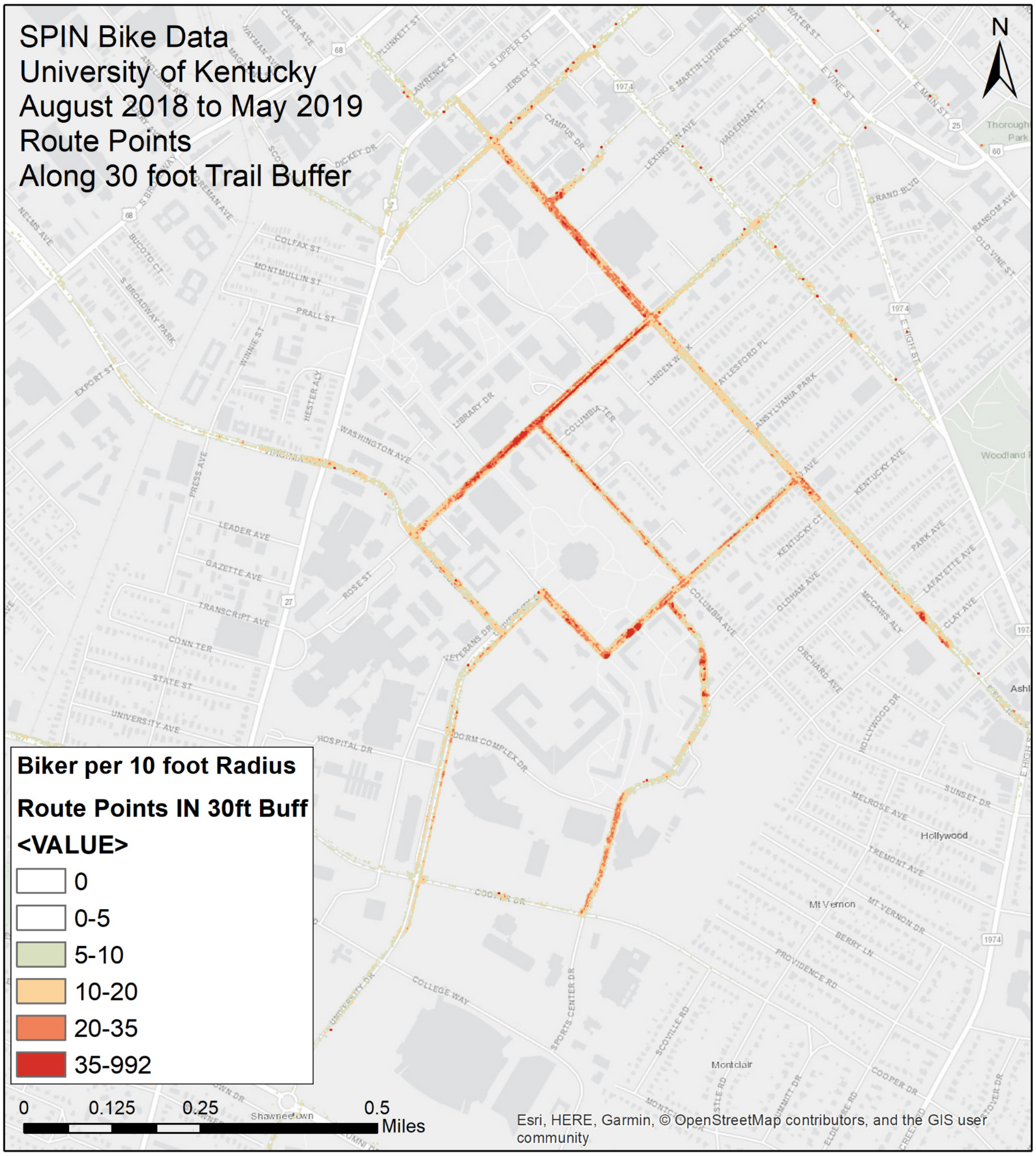


Figure 4.12 Travel demand on existing bicycle facilities

The second part of this analysis is to examine the bicycle travel usage for routes that were completed along areas lacking any bicycle infrastructure as defined earlier. This can be done by clipping, or removing, any Route Points that are located within a certain distance from the centerline of the existing bicycle facility. For this research, a radial distance of 30 feet from the centerline of the bicycle facilities has been used to remove Route Points on these facilities. The 30-foot buffer radius was decided in order to address the possibility that a bicyclist may have used another part of the facility adjacent to the actual route (for example someone riding on a sidewalk next to a bicycle lane) or to address the inaccuracy of the bicycle's GPS tracker. Figure 4.13 shows a point density map of the remaining Route Points that are not along an existing bicycle infrastructure. This map will be used to identify locations and routes that have heavy bicycle traffic but without any bicycle infrastructure or designated facility. The data in Figure 4.13 show that there is high demand for a corridor connecting the north and south ends of the campus.

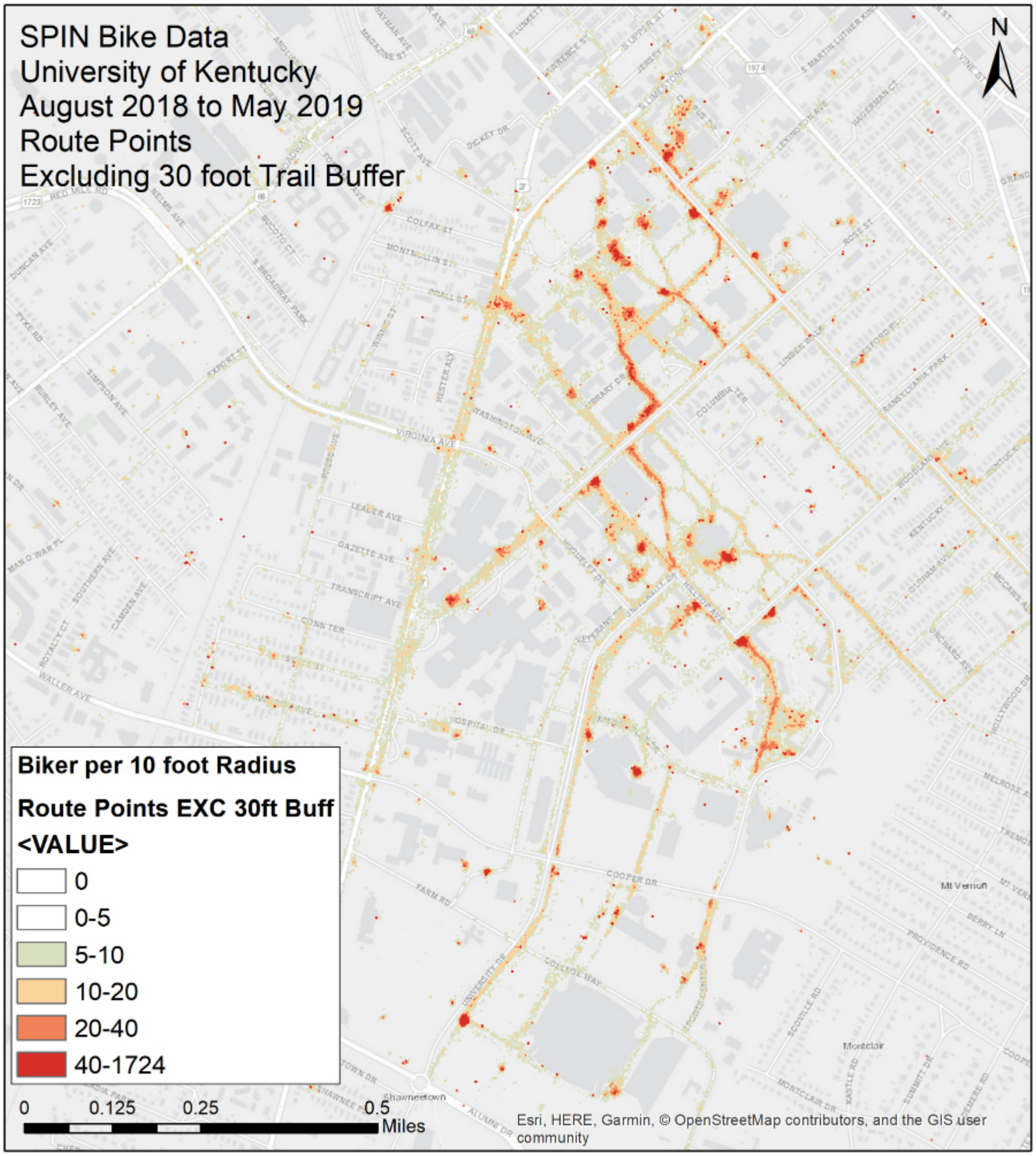


Figure 4.13 Travel demand along non-bicycle facilities

4.4.2 Parking Analysis

The introduction of SPIN bicycles has increased the demand for bicycle parking on UK campus, specifically around classroom buildings and resident halls. UK has been placing signs by trees that frequently have bicycles locked to them with hopes to encourage students to use designated parking facilities instead. However, as Figure 4.14 shows, students are disregarding these signs and still locking their bicycle to a tree or other objects, like the light pole in Figure 4.14. SPIN bicycle trip data can be used to identify locations where additional bicycle parking is needed to meet demands. This will be done through an analysis of the areas with high density Start and End Points. The UK infrastructure data included the locations of existing bicycle parking facilities on within UK campus.

a. light pole

b. tree

Figure 4.14 Inappropriate bicycle locking

Bicycles used through the dockless SPIN bicycle share program can be left anywhere that is permitted to leave a bicycle which is not necessarily a bicycle parking facility. A dockless bicycle share system provides additional insight as to where bicycles have the tendency of being left without the potential consequences if the bicycle was owned, such as theft or vandalism. For example, a bicyclist may leave a SPIN bicycle outside a classroom building. However, if the bicyclist owned the bicycle, they will most likely lock it to a bicycle rack for security. Some common locations that bicyclists leave SPIN bicycles are next to a classroom or office building, in the grass near a sidewalk, and at or near a bicycle rack as shown in Figure 4.15.

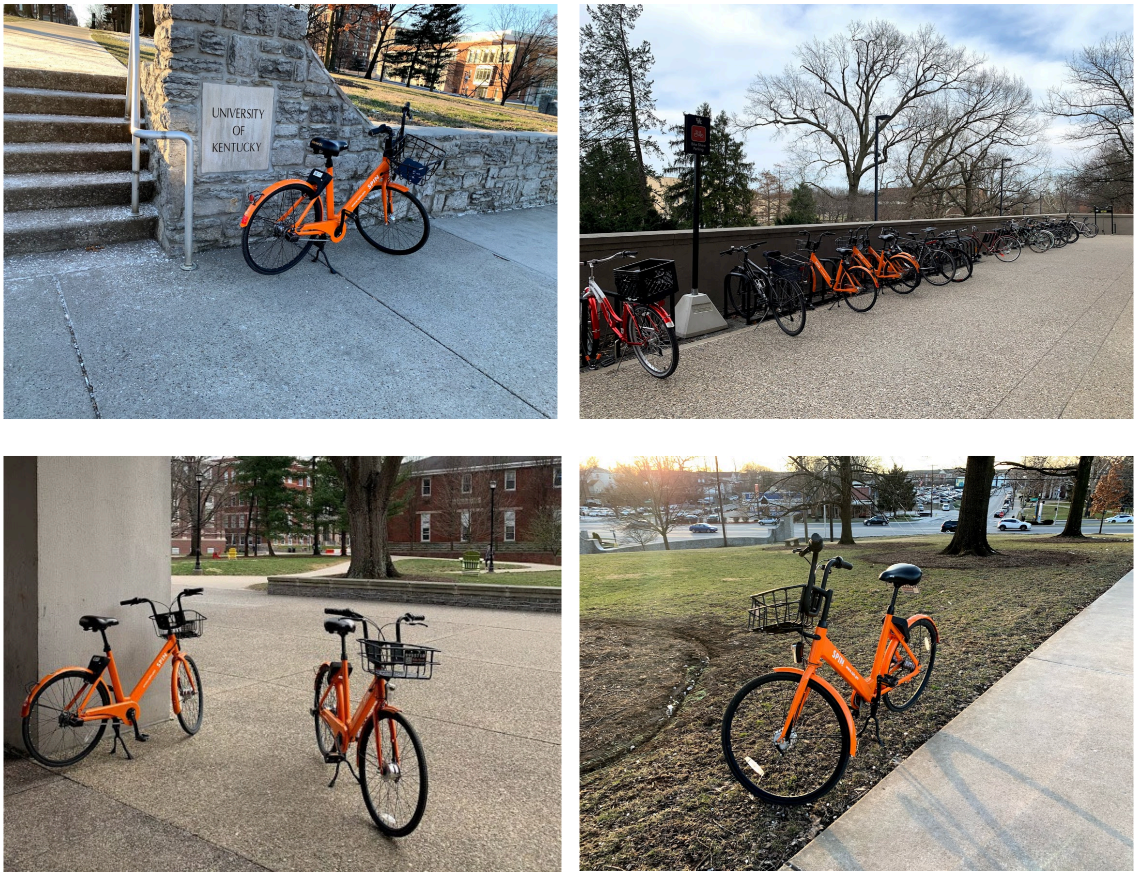


Figure 4.15 Common SPIN bicycle locations

The points used for analyzing existing bicycle parking facilities are the Start Points and End Points. The objective is to determine where bicycle parking is being properly utilized and where additional bicycle parking may be needed. To begin, the Start and End Points are displayed on the map and merged into one set of points for this analysis, since an end location will then turn into a start location when a new user finds an available SPIN bicycle. A point density map can be used to show areas of high beginning and ending trip locations (Figure 4.11). High density areas can be seen in the core of campus, near Patterson Office Tower and Whitehall Classroom. On south campus, there are high density areas near the student dorms and the main campus library (William T Young Library).

The existing bicycle parking infrastructure will be considered in this analysis. The point density map in Figure 4.16 can be used in combination with the map of the existing bicycle parking racks (Figure 4.11). For this analysis, any Start or End Points that are located within a 50-foot radius of an existing bicycle parking rack will be clipped to show only the Start and End Points that are not located near a bicycle parking rack. It was determined that only about 21 percent of the SPIN bicycle trips started or ended within 50 feet of an existing bicycle parking rack. Figure 4.17 is the resulting point density map showing high density areas where the remaining 79 percent of SPIN bicycle trips started or ended outside of the set 50-foot radius of an existing parking location. This map will assist in determining locations that could benefit from either expanding the existing bicycle parking rack or installing a new bicycle parking rack. One limitation in this analysis is that the size and shape of the parking rack was not considered. Therefore, a 50-foot radius may overestimate or underestimate the area depending on whether the parking rack is small or exceeds the radius. Figure 4.17 shows that there are several locations where there is a high concentration of bicycles and identifies the need for additional facilities that will be discussed in the next section.

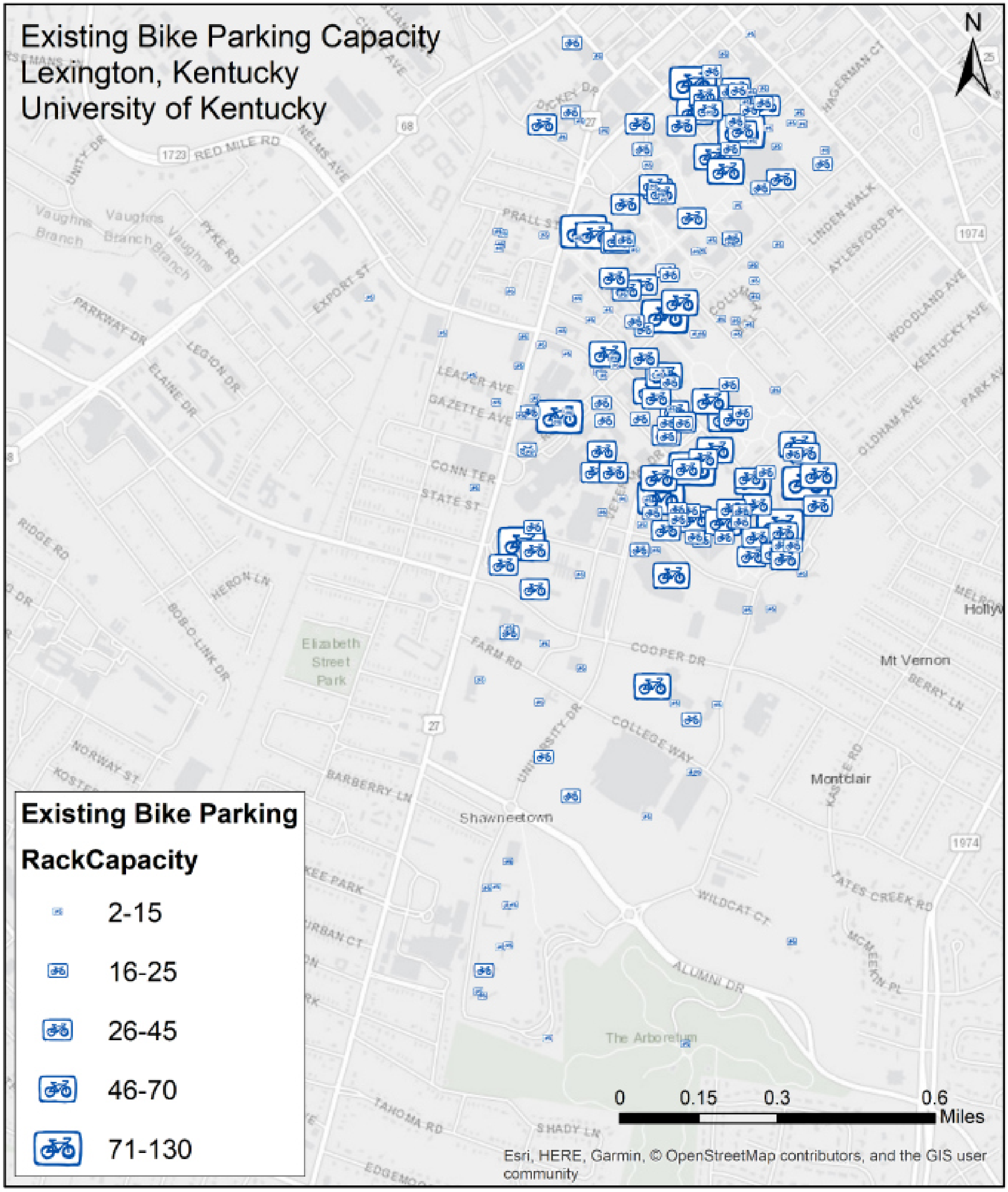


Figure 4.16 Existing bicycle parking on UK campus

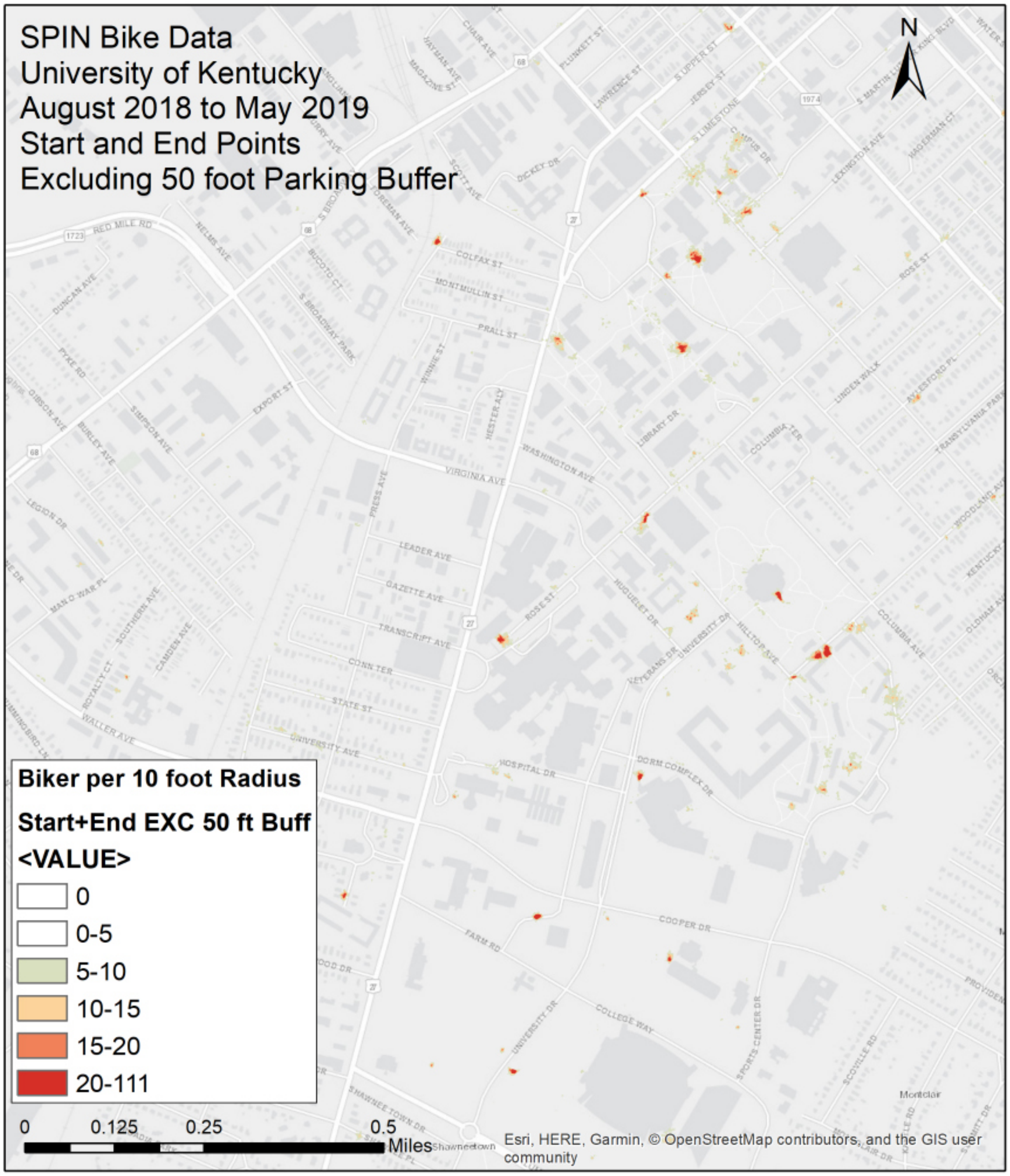


Figure 4.17 Start and end points away from existing bicycle parking

CHAPTER 5. RECOMMENDATIONS

The objective of the analysis presented here is to identify areas where demand exceeds supply, i.g., bicycle infrastructure, and identify areas where improvements may be needed. To achieve this, the focus of the data shown in Figure 4.13 (routes) and Figure 4.17 (parking) is on the red and orange clusters indicating high bicycle travel and parking demand. Therefore, new or improved bicycle facilities should be considered for these areas. Locations requiring bicycle infrastructure improvements are developed based on this assumption and depict the routes and parking locations that seem to be candidates for additional evaluation in order to determine what infrastructure improvements may be needed. Four routes and four bicycle parking locations have been identified through this process. These routes and locations will be further analyzed to determine appropriate design to meet travel demands.

5.1 Route Recommendations

Figure 5.1 is a map with the recommended routes that could benefit from a bicycle facility. Four routes have been identified to improve the bicycle infrastructure along these heavily traveled paths that are without a bicycle facility. Three of the four routes (Routes 1 – 3) are internal to UK campus while the fourth route (Route 4) is along South Limestone. The routes within campus demonstrate the need for higher connectivity between the north and south parts of the campus as well as within the campus area. The path along South Limestone indicates the need for connectivity between the campus and the city though it may be more difficult to address this need given the vehicular travel demands along this corridor.

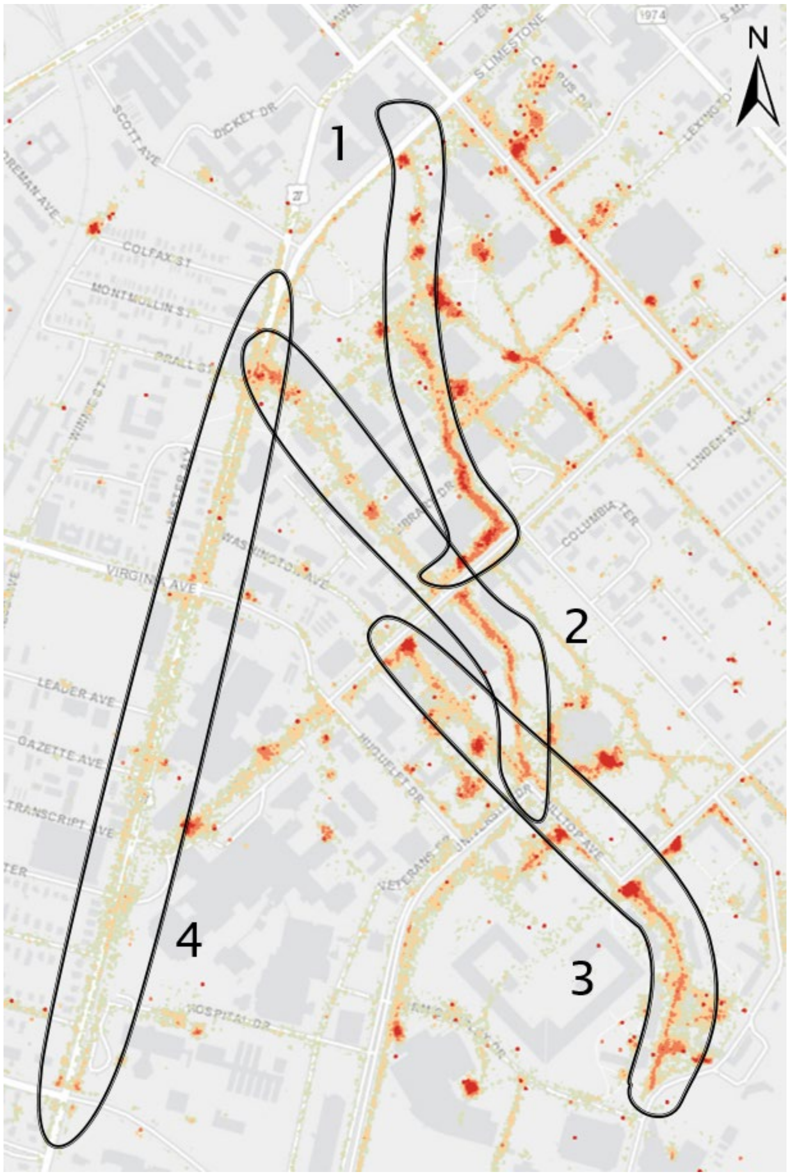


Figure 5.1 Recommended improved bicycle routes

The research team has worked closely with the UK senior level Landscape Architecture class to develop conceptual designs for the recommended bicycle routes. The class presented alternatives during the UK Landscape Architecture Design Week. Conceptual drawings for each route are included in Appendix A. The majority of the designs focuses on connecting Routes 1, 2 and 3 to create a continuous path from the north end of campus to the south end. The plans use existing sidewalks and walking areas where a shared path was created for both bicyclist and pedestrians. Route 4 developed a plan for the section of South Limestone between Cooper Drive and Scott Street where a bidirectional bicycle facility was proposed in the place of the two-way left-turn lane. It should be noted that these designs are conceptual and preliminary and additional evaluation is needed in the future so details could be addressed in order to make them feasible projects for implementation.

5.2 Parking Recommendations

Figure 5.2 presents the recommended locations for adding bicycle parking racks or expanding existing bicycle parking racks based on the high density locations in Figure 4.17. The gray points in Figure 5.2 are locations of existing bicycle parking racks while the other red colored areas depict need for bicycle parking facilities. The locations of the existing bicycle parking racks are shown in order to determine whether the recommendation is expansion of existing parking or addition of a new parking rack. Four locations have been identified as requiring improved or additional bicycle parking and all are within the UK campus. Two of the locations are in the vicinity of residence halls (Location 1 and Location 3), one is near major classroom buildings (Location 2), and another (Location 4) is at the UK Football stadium parking lot where many faculty and commuters park their vehicles and ride the LexTran buses to main campus. Figure 5.2 shows that there are some areas that require a revisit of the facilities provided, i.e., update or expansion of the existing parking facility. This could be the case for Locations 1, 2 and 4. However, Location 3 suggests that there is a need for the introduction of a bicycle parking rack since one does not exist where the high-density areas are shown. Location 3, near the Woodland Glen residence halls, may need to be expanded or provide another parking rack.

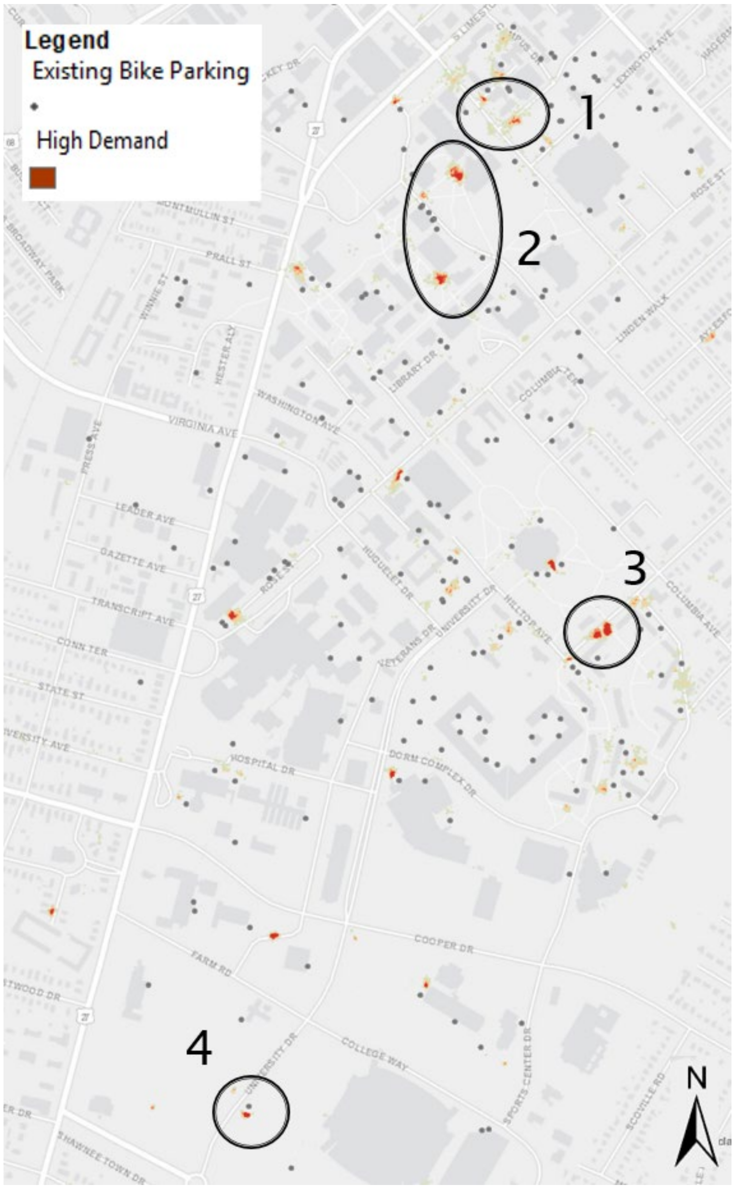


Figure 5.2 Recommended improved bicycle parking locations

Recommendations for addressing the need for more bicycle parking include expanding existing bicycle parking and adding new parking facilities. The demanded bicycle rack capacity will be reported for each recommended location using the point density map (Figure 5.2). The daily count of Start and End points within the dark red region of each of the four recommended locations was first determined. The maximum number and average number of daily count was reported and compared to the existing number of parking spaces, if applicable (Table 5.1). It is important to note that the reported count numbers are only those that are SPIN bicycles and do not include the number of bicycles that are personally owned.

Table 5.1 Bicycle parking need

Location	Total Trips	Daily Count		Existing Capacity
		Maximum	Average	
1 (East)	122	6	0.5	0
1 (West)	297	8	1.4	54
2 (North)	124	4	0.5	0
2 (South)	238	8	0.9	0
3	546	13	2.1	0
4	1269	28	4.9	20

Location 1 would benefit with the expansion of 6 parking spaces to the east of Location 1 since this area does not have an existing bicycle rack. The west area in Location 1 has an existing bicycle rack with capacity greatly exceeding the maximum SPIN bicycle demand. This difference could be attributed to the potential use of the rack by other users and therefore the SPIN bicycles were able to be left dockless. Both red areas within Location 2 do not have an existing bicycle facility. The southern red area is located at the

White Hall Classroom which is one of the major classroom buildings and the northern red area is located near the student center. Both areas in Location 2 would benefit with the addition of a bicycle rack with the rack capacity at least the maximum daily count as shown in Table 5.1. These areas appear to have the demand for 4 to 8 parking spots. The red areas in Location 3 are located at the main sidewalk entrance to the Woodland Glen residence halls which is a major starting and ending location of SPIN bicycle usage. The existing parking facilities in this region appear to meet the demands of bicycle parking. It is recommended to add another bicycle parking facility where the red area is located. Location 4 is at the UK football stadium parking lot near the bus stop for the LextTran UK campus route. It is recommended that the existing parking facility be expanded to meet the demand for a maximum of 28 parking spots. The existing parking rack has a capacity of 20 spots.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The use of GPS devices has been a major aid for tracking bicycle trips and having access to bicycle trip data for research. City planners can use such data to determine the best way to allocate funds for improving bicycle infrastructure. The installation of new or improved bicycle infrastructure has the ability to provide cyclists with safe and efficient travel routes.

This study examined bicycle travel demand and travel patterns as generated by SPIN bicycle users. Data from the bicycle share company, SPIN, was provided in order to evaluate the travel patterns and travel demand for the bicycle share pilot program. The data was processed and analyzed in order to address temporal and climatic effects, define temporal and travel-related variables that could predict travel demand, and determine infrastructure needs through a point density analysis. Maps were created as the product of the point density analysis to provide insight to ways to improve bicycle routes and bicycle parking. Existing bicycle facilities were considered in order to determine where to recommend new bicycle paths and bicycle parking. As a result, four routes and four parking locations were identified as the high demand areas. Conceptual design ideas were created through the collaboration with Landscape Architecture students.

Overall, the analysis indicate bicycle trips are influenced by weather conditions, travel time, and travel distance. Bicycle travel demand fluctuates with weather patterns. Various weather characteristics can be used to predict daily bicycle usage such as precipitation, wind speed, and temperature. However, the elasticity of bicycle travel demand may vary based on culture and dependency on cycling. Bicycle-friendly cities, like Copenhagen, Denmark, most likely do not see a dramatic drop in bicycle usage in the presence of rain. In places where cycling is a small percentage of mode choice and individuals may have the option to drive a car, such as it is the case in the United States, a larger decrease in bicycle travel demand when adverse weather conditions are present may be seen.

Based on the data and point density analysis, it is apparent that bicycle infrastructure influences the travel paths cyclists take. Travel demand on routes without an existing bicycle facility varies depending on the bicyclists' comfort and perceived safety on that route. For example, non-bicycle routes within UK campus showed heavy travel demand whereas South Limestone showed less travel demand. This could be due to the perceived differences in the safety level along each corridor based on vehicle volume and travel speeds. The travel demand for cycling can be used to identify areas to supply bicycle infrastructure where it is appropriate.

The analysis of the Start and End points showed that a high-density area was located at the LexTran bus stop near the stadium parking lot. This supports the idea that commuters are using SPIN bicycles to chain their trips with transit and completing the last or first section of the trip with a bicycle. Bicycle share can be seen as a way to connect individuals to and from transit stops and solving the "last mile" problem. One factor that plays a role in the success of trip chaining with cycling is having adequate parking spots to meet the demand. Recommendations for expanding the existing bicycle parking facility at the LexTran bus stop were provided.

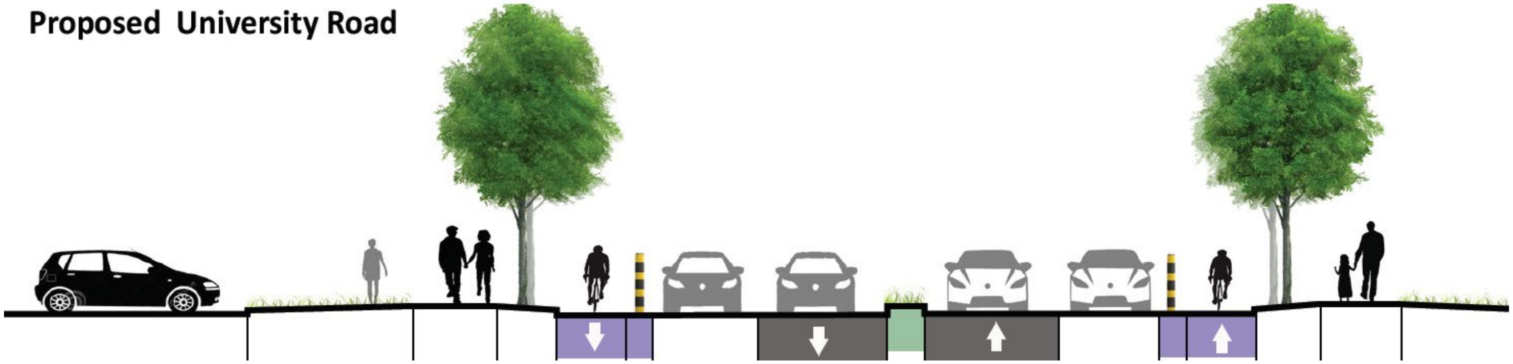
Future work could use the existing data and conduct a more detailed analysis on the individual trip level to determine what percentage of a completed trip was taken on an existing bicycle facility or on a non-facility. Common detours could be identified by locating where certain routes or areas are avoided. These findings could aid transportation planning officials to make decisions for expanding the existing bicycle network in efforts to minimize the percentage of cyclists who take a detour and the length of detours when necessary.

The UK Transportation Services and the LFUCG Division of Planning/Traffic Engineering could use these findings and conclusions to aid their decisions to improve the bicycle network throughout UK campus and to connect campus to the city of Lexington. Successful improvements and connectivity have the ability to make cycling as a mode of transportation more enticing for students and faculty as well as for the residents of Lexington.

APPENDIX

This appendix includes conceptual designs created by UK Landscape Architecture. It should be noted that these designs are conceptual and preliminary and additional evaluation is needed in the future so details could be addressed in order to make them feasible projects for implementation.

University Drive



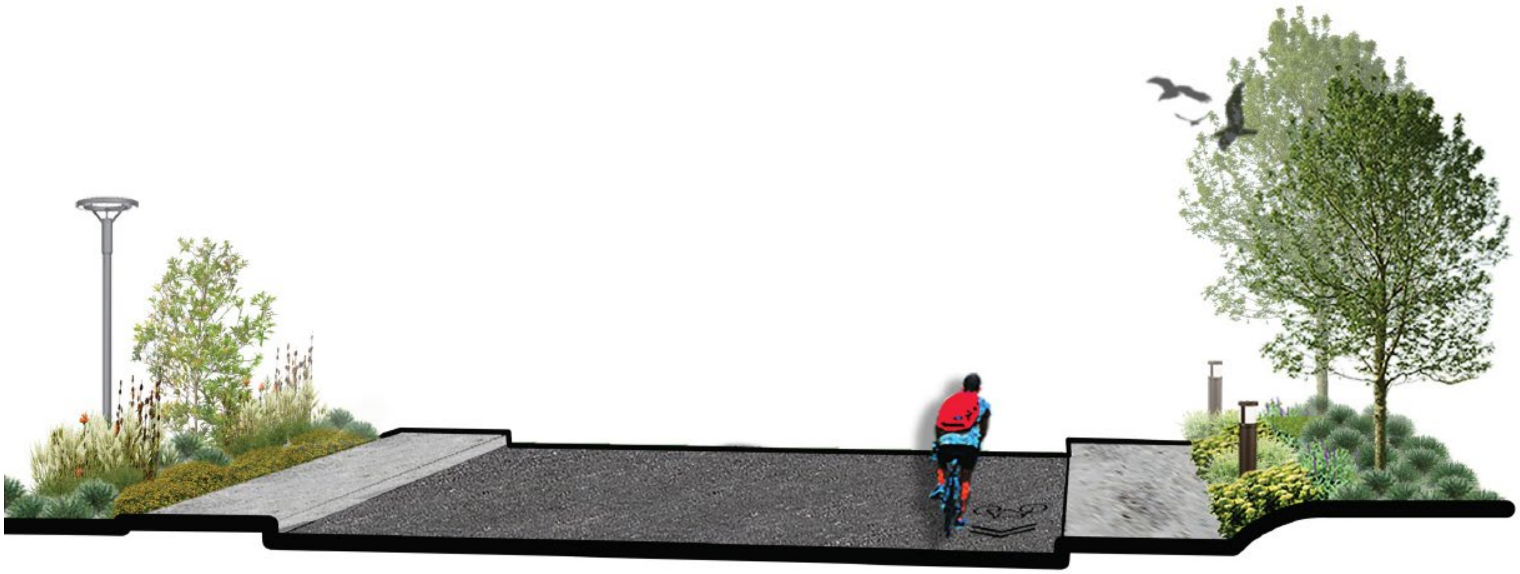
Farm Road

Proposed Farm Road

Washington Avenue

WASHINGTON AVE.

Gladstone Avenue



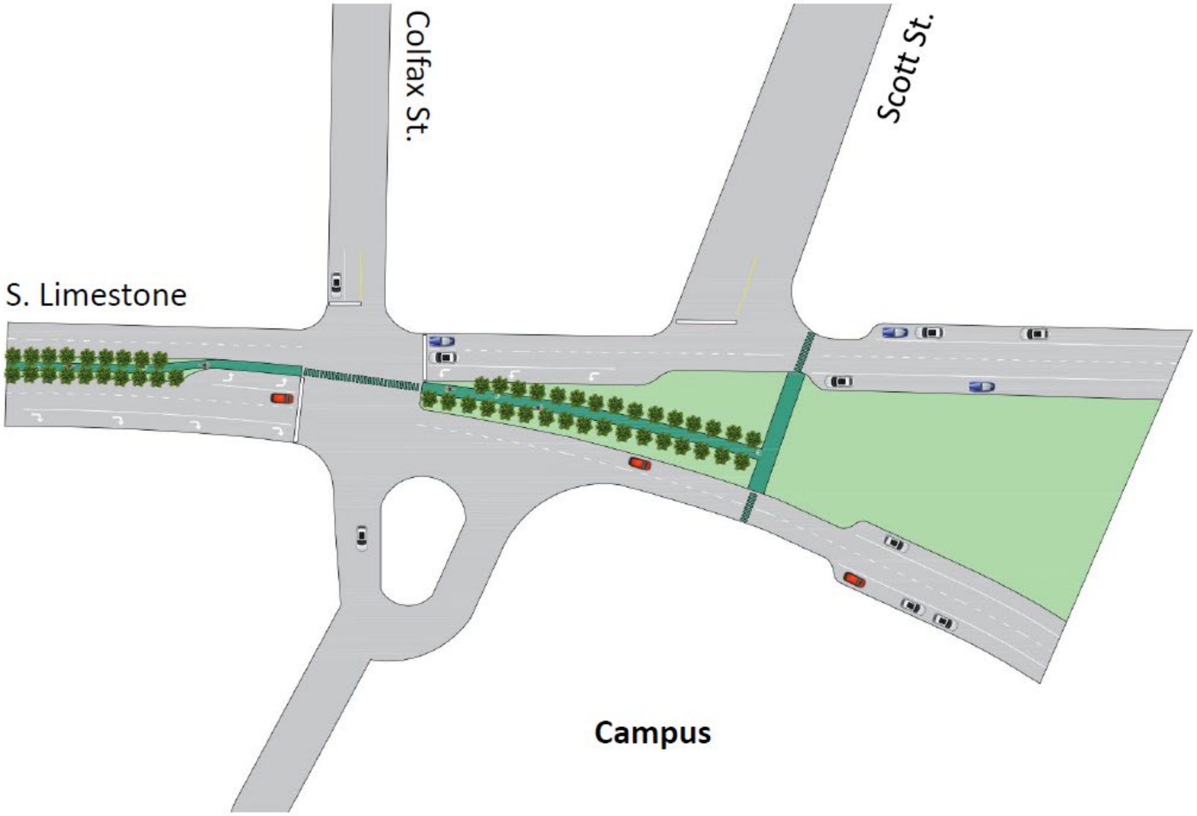
GLADSTONE AVE.


Master Plan
Legend
Single Direction Bike Lane
Dual-Direction Bike Lane
● Intersection with Bike Signals
● Intersection with Legal U-Turn
● Remove Intersection

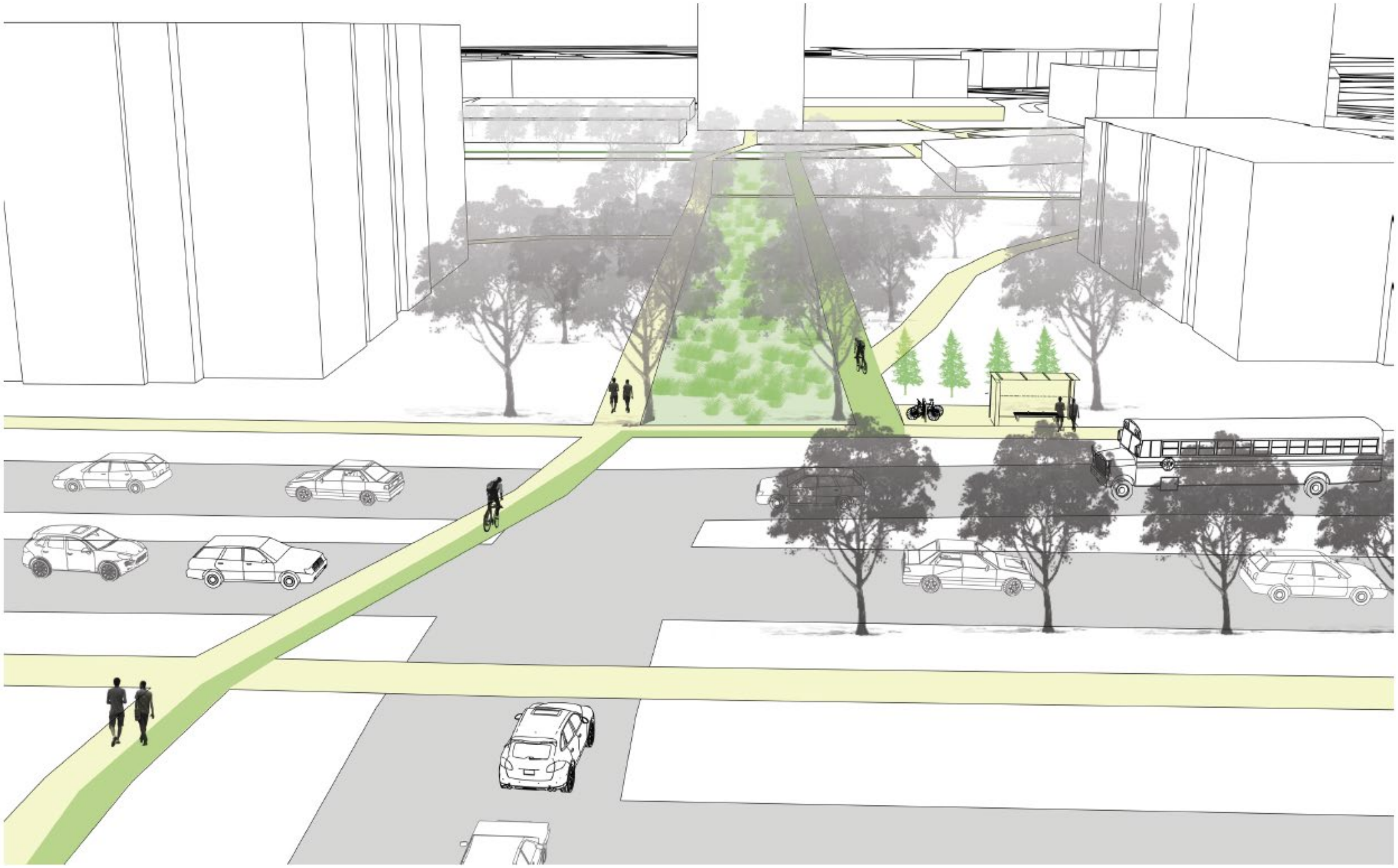
South Limestone

Colfax and South Limestone Intersection

Intersection Diagram: Colfax & S. Limestone



University Drive and Huguelet Drive Intersection



Sports Center Drive and University Drive Intersection

Oak Allee


OAK ALLEE
PLANTING
BIKEWAY
PLANTING
SIDEWALK
PLANTING
CYCLING AMENITIES

Woodland Glen Corridor

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